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# **Joint study of inorganic and hydrocarbon components of tropospheric aerosol in the atmosphere over the boreal area of the south of Western Siberia by using the "Optik" Tupolev-134 aircraft laboratory**

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## **ABSTRACT**

The article provides a joint analysis of the aerosol chemical composition data on the content of inorganic components (chemical elements and ions) and hydrocarbons (n-alkanes) as part of an aerosol over Karakansky bor (a large forest with prevailing coniferous trees on the right bank of the southern part of the Novosibirsk reservoir) in aircraft sounding from 2011 to 2016. Correlation analysis showed the greatest connection with n-alkanes of three metals - copper, cobalt and aluminum, especially copper and cobalt, with 5-6 hydrocarbon homologues right away Sodium, potassium, calcium and barium correlate with 1-2 n-alkanes. Soil aluminum and silicon, and a number of other trace elements find a connection with 1-3 n-alkanes. The homologs that are often correlated with one metal are consistently in the same row, which may indicate a significant catalytic activity of this metal in the atmosphere.

**Keywords:** atmospheric aerosol, elemental and ionic composition, volatile organic compounds (VOC), hydrocarbons.

## **1. INTRODUCTION**

Atmospheric aerosol is one of the most volatile components of air and plays an important role in many processes, such as the scattering and absorption of solar radiation, which largely determine the heat balance of the planet, the formation of clouds, changing the albedo of the globe. This role depends on the size and chemical composition of the aerosol particles. The chemical composition of the aerosol also determines its ecological significance: the effect on biological objects and elements of the environment. Until recently, it was believed that the chemical composition of atmospheric aerosol is determined by inorganic components, and organic components are only a few percent in the total aerosol balance.<sup>1</sup>

Studies of the previous two decades have shown that the role of organic compounds plays a much more important role in aerosol physics than was previously thought.<sup>2</sup> Organic compounds largely determine the process of formation of nanoparticles<sup>3-5</sup>, and, thus, give rise to the entire aerosol process in the atmosphere.

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Currently, there is no doubt that organic compounds in the composition of aerosols are present throughout the entire troposphere and interact with the inorganic components of the aerosol.<sup>1, 6-8</sup> It is obvious that the sources of organic and inorganic components of the aerosol in most cases are different. However, there is no doubt that the components of different chemical types will interact in the atmosphere and the patterns of these interactions will be reflected in the ratios of these components in the composition of the aerosol.

## 2. SITES AND METHODS OF MEASUREMENTS

Airborne sounding of the atmosphere on the aircraft laboratory Tupolev-134 "Optik" held since March 2011, with an almost monthly basis in the tropospheric layer up to 7 km above conditionally background area Karakansky bor, located 100-200 km south-west of Novosibirsk on the border with the Altai Region (Fig. 1).



Figure 1. Horizontal track of typical flight of the aircraft laboratory Tupolev-134 "Optik" on the map of Novosibirsk region.

Since December 2011, in addition to the traditional sampling of atmospheric aerosol on Petryanov filters with subsequent analysis on the content of inorganic ions and elements<sup>9</sup>, we have been developed systematic sampling of aerosol-forming volatile organic compounds on teflon filters GRIMM 1.113A with further analysis on the content of saturated hydrocarbons by GC-MS<sup>10</sup>.

It was originally intended to carry out a selection during horizontal flight at altitudes of 0.5; 1.0; 1.5; 2.0; 3.0; 4.0; 5.5 and 7.0 km, that is, at those levels where air was sampled to analyze the content of greenhouse gases and the inorganic fraction of the aerosol. But since the concentrated substance was not enough to exceed the detection threshold of many organic compounds, the entire altitude range was divided into two layers: 0.5–2.0 km and 3.0–7.0 km. The first altitude range characterizes the content of organic compounds in the boundary layer of the atmosphere, the second - in the free atmosphere.

### 3. RESULTS

A joint study of the organic and inorganic components of atmospheric aerosol for the period from 2011 to 2016 showed the following results. When constructing the mass-average chemical matrix of the aerosol from the determined inorganic ions and elements with the inclusion in it of the total mass content of n-alkanes, the ratio of their total contents is about 1000 to 1.3 (Fig. 2). The total concentration of the constructed matrix is 7.92  $\mu\text{g}/\text{m}^3$ . The number of averaged pairs of samples - 38.

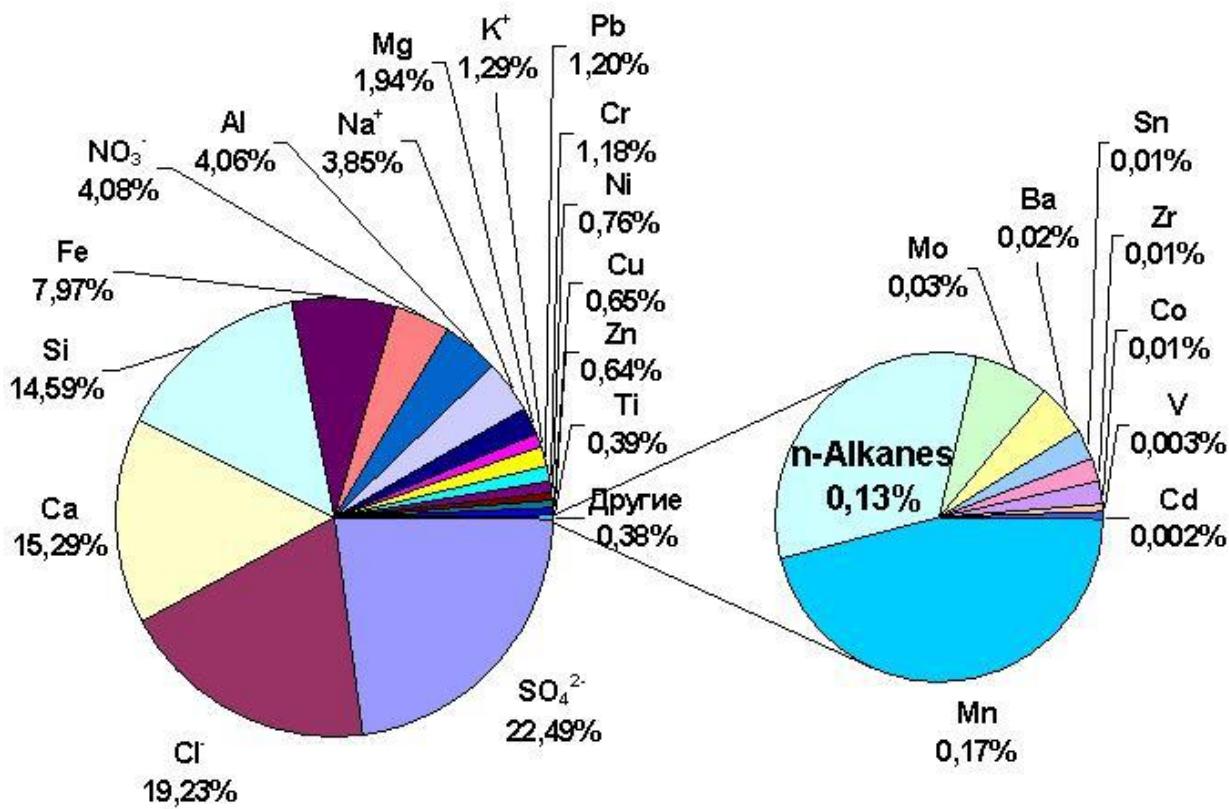


Figure 2. Average for the period of joint measurements 2011-2016 ion and element matrix of the aerosol, taking into account the determined amount of n-alkanes (wt.%).

For the region of constant measurements on a sample of the majority (32 of 38) of the integral samples of n-alkanes, combined with the results of the analysis of samples of the inorganic component, a correlation analysis was performed. The part of the correlation matrix combining inorganic components and n-alkanes with statistical security sufficient for building correlations is given below in Table 1. The bottom and rightmost lines show the number of samples with nonzero (above the detection limit) values of the corresponding components. The correlation coefficients significant in the  $q = 0.95$  level in the table are in bold.

Table 1. Correlation matrix of average mass concentrations of n-alkanes in the amount (Alk.Sum) and individually (C12 to C27) with the average height of the sensing layer and the average concentrations of inorganic components separately and in the amount (InorgSum)

|         | <i>Altitude</i> | <i>Al</i>     | <i>Ba</i>     | <i>Ca</i>     | <i>Cu</i>     | <i>Fe</i> | <i>Mg</i> | <i>Mn</i> | <i>Mo</i> |
|---------|-----------------|---------------|---------------|---------------|---------------|-----------|-----------|-----------|-----------|
| Alk.Sum | -0,2307         | <b>0,3104</b> | 0,2833        | -0,0645       | <b>0,3832</b> | 0,0815    | 0,1855    | 0,0472    | -0,0099   |
| C12H26  | -0,1855         | -0,1099       | -0,3028       | 0,1052        | -0,2430       | -0,0866   | 0,0528    | -0,1916   | -0,1060   |
| C13H28  | 0,2359          | -0,1820       | -0,1146       | -0,0470       | -0,0430       | -0,0121   | -0,0423   | -0,0353   | 0,0318    |
| C14H30  | 0,1950          | -0,0120       | 0,1553        | 0,0831        | <b>0,4585</b> | 0,2553    | 0,1850    | 0,0326    | 0,1993    |
| C15H32  | 0,0579          | 0,1246        | 0,0820        | <b>0,3307</b> | -0,0575       | 0,1883    | 0,2055    | -0,0617   | 0,0711    |
| C16H34  | 0,0181          | <b>0,3716</b> | <b>0,4258</b> | -0,0260       | -0,0010       | 0,1087    | 0,1761    | 0,0255    | 0,0313    |
| C17H36  | -0,1724         | 0,1910        | 0,1270        | 0,2842        | 0,2301        | 0,2266    | 0,1275    | -0,0221   | -0,0860   |
| C18H38  | -0,0906         | -0,0131       | 0,0191        | -0,0535       | 0,2620        | -0,0257   | -0,0544   | -0,0015   | -0,1076   |
| C19H40  | -0,1312         | -0,0054       | -0,0081       | -0,1048       | <b>0,3393</b> | -0,0572   | -0,0373   | 0,0034    | -0,0877   |
| C20H42  | -0,0913         | 0,0094        | 0,0225        | -0,1283       | <b>0,4225</b> | -0,0077   | -0,0144   | 0,0311    | -0,1130   |
| C21H44  | <b>-0,3214</b>  | 0,2405        | 0,0715        | -0,1054       | 0,2766        | 0,0536    | 0,1186    | 0,0951    | -0,0065   |
| C22H46  | <b>-0,3287</b>  | 0,1143        | 0,0682        | -0,1117       | 0,2890        | 0,0067    | 0,0537    | 0,0232    | 0,0376    |
| C23H48  | <b>-0,3568</b>  | <b>0,3667</b> | 0,2166        | -0,0725       | 0,2793        | 0,1109    | 0,2387    | 0,1445    | 0,0586    |
| C24H50  | -0,2404         | 0,1195        | 0,1484        | 0,0017        | <b>0,5127</b> | 0,0822    | 0,2136    | 0,0750    | -0,0021   |
| C25H52  | -0,1376         | 0,3672        | <b>0,4555</b> | -0,0475       | <b>0,4518</b> | 0,2299    | 0,2801    | 0,1233    | 0,0942    |
| C26H54  | -0,1367         | 0,1685        | 0,1893        | -0,0508       | <b>0,4781</b> | -0,0650   | 0,2420    | 0,0272    | 0,0678    |
| C27H56  | -0,2469         | 0,3604        | 0,2404        | -0,1183       | -0,0840       | -0,0210   | 0,1541    | 0,0326    | -0,0028   |
| N =     | 32              | 32            | 21            | 32            | 31            | 31        | 32        | 28        | 31        |

|         | <i>Ni</i> | <i>Pb</i> | <i>Sn</i>     | <i>Ti</i> | <i>V</i>      | <i>Cd</i> | <i>Si</i>     | <i>Co</i>     | <i>Cr</i>     |
|---------|-----------|-----------|---------------|-----------|---------------|-----------|---------------|---------------|---------------|
| Alk.Sum | 0,0030    | 0,0031    | 0,2248        | 0,1162    | 0,1665        | -0,0987   | 0,2554        | <b>0,3897</b> | 0,0282        |
| C12H26  | -0,2092   | -0,2311   | -0,0839       | -0,0883   | 0,0987        | -0,0730   | -0,0661       | -0,1752       | 0,0034        |
| C13H28  | 0,0419    | 0,1502    | -0,1155       | -0,0988   | -0,1156       | -0,0801   | -0,1517       | -0,1572       | 0,0244        |
| C14H30  | 0,2582    | 0,2861    | <b>0,4719</b> | -0,0150   | 0,2175        | -0,1068   | -0,0722       | 0,0371        | <b>0,6293</b> |
| C15H32  | 0,2300    | -0,0518   | 0,0561        | 0,2053    | <b>0,3978</b> | -0,0836   | 0,1071        | <b>0,4792</b> | 0,0601        |
| C16H34  | -0,0517   | -0,1412   | -0,0087       | 0,1278    | 0,3027        | -0,0768   | <b>0,3731</b> | 0,2636        | -0,0747       |
| C17H36  | 0,2182    | 0,0367    | 0,2349        | 0,0830    | 0,2883        | -0,1869   | 0,1175        | <b>0,3816</b> | 0,1506        |
| C18H38  | 0,0485    | -0,0222   | 0,0245        | 0,0446    | 0,0575        | -0,1121   | -0,0200       | 0,1885        | -0,0842       |
| C19H40  | -0,0100   | 0,0169    | 0,0486        | 0,0124    | -0,0318       | -0,1443   | -0,0365       | 0,1465        | -0,0867       |
| C20H42  | 0,0623    | 0,0314    | 0,1571        | 0,0957    | -0,0071       | -0,1127   | -0,0923       | 0,2672        | -0,0475       |
| C21H44  | 0,0035    | 0,1350    | 0,1154        | 0,1523    | -0,0933       | -0,1246   | 0,1213        | <b>0,3623</b> | -0,1282       |
| C22H46  | 0,0658    | 0,0738    | 0,1776        | 0,1157    | -0,0359       | -0,1201   | -0,0681       | <b>0,3608</b> | -0,0697       |
| C23H48  | -0,0309   | 0,1464    | 0,2397        | 0,1275    | 0,0067        | -0,1503   | 0,2943        | 0,3318        | 0,0532        |
| C24H50  | 0,1309    | 0,1236    | <b>0,4661</b> | 0,2420    | 0,0926        | -0,0874   | -0,0162       | <b>0,4655</b> | 0,2671        |
| C25H52  | 0,0638    | 0,1017    | <b>0,5186</b> | 0,0772    | 0,2753        | -0,1039   | 0,3308        | 0,2101        | <b>0,4620</b> |
| C26H54  | -0,0600   | -0,0252   | 0,3011        | 0,3493    | 0,0316        | 0,3709    | 0,1330        | 0,3564        | 0,0976        |
| C27H56  | -0,2264   | -0,1141   | -0,0971       | -0,0321   | 0,0304        | -0,0170   | 0,4451        | 0,1202        | -0,2153       |
| N =     | 28        | 28        | 17            | 32        | 27            | 11        | 32            | 27            | 29            |

|         | Zn      | Zr            | $Na^+$        | $K^+$         | $Cl^-$  | $NO_3^-$ | $SO_4^{2-}$ | Inorg.Sum | M = |
|---------|---------|---------------|---------------|---------------|---------|----------|-------------|-----------|-----|
| Alk.Sum | 0,1806  | 0,1480        | 0,2050        | -0,0746       | -0,0688 | 0,0297   | -0,1371     | 0,0008    | 32  |
| C12H26  | -0,0110 | -0,1359       | -0,1458       | 0,3160        | -0,0338 | -0,1556  | -0,0312     | -0,0264   | 16  |
| C13H28  | -0,1256 | -0,1228       | -0,1516       | 0,0627        | -0,1748 | -0,1731  | -0,0328     | -0,1349   | 8   |
| C14H30  | 0,0502  | 0,1930        | -0,0129       | 0,2947        | 0,0566  | -0,0372  | 0,0553      | 0,1154    | 27  |
| C15H32  | 0,0114  | <b>0,4057</b> | 0,1075        | <b>0,3519</b> | -0,0333 | -0,1028  | -0,0125     | 0,1846    | 31  |
| C16H34  | 0,1571  | 0,0766        | -0,1469       | -0,0824       | -0,1527 | -0,1017  | -0,1472     | -0,0192   | 32  |
| C17H36  | 0,0481  | 0,3844        | 0,2235        | 0,0526        | 0,1114  | -0,0347  | 0,0590      | 0,2467    | 32  |
| C18H38  | 0,0285  | 0,1297        | 0,1961        | -0,1707       | -0,0396 | 0,0226   | -0,1252     | -0,0765   | 32  |
| C19H40  | 0,0525  | 0,0394        | 0,2281        | -0,2011       | -0,0662 | 0,0245   | -0,1523     | -0,1179   | 32  |
| C20H42  | 0,1143  | 0,0568        | 0,2612        | -0,2131       | -0,0865 | 0,0397   | -0,2133     | -0,1530   | 31  |
| C21H44  | 0,1356  | 0,0565        | 0,2409        | -0,2171       | -0,1647 | -0,0802  | -0,2044     | -0,1105   | 31  |
| C22H46  | 0,0852  | 0,0635        | 0,2595        | -0,1718       | -0,1512 | -0,0348  | -0,2754     | -0,1775   | 29  |
| C23H48  | 0,2068  | 0,0958        | 0,1898        | -0,0261       | -0,0418 | -0,0582  | -0,0867     | 0,0321    | 24  |
| C24H50  | 0,2871  | 0,1578        | <b>0,3624</b> | 0,0671        | 0,0343  | 0,1290   | -0,1141     | 0,0348    | 24  |
| C25H52  | 0,2636  | 0,1934        | 0,0279        | 0,2099        | 0,1229  | 0,0527   | 0,0142      | 0,1571    | 15  |
| C26H54  | 0,3491  | 0,0578        | <b>0,5472</b> | 0,0477        | 0,1339  | 0,5793   | 0,1404      | 0,1850    | 14  |
| C27H56  | 0,0827  | -0,0810       | -0,0688       | -0,0100       | -0,0781 | -0,0433  | -0,0170     | 0,0101    | 12  |
| N =     | 30      | 21            | 32            | 30            | 30      | 27       | 30          | 32        |     |

#### 4. DISCUSSION AND CONCLUSION

Analysis of the correlation matrix shows the greatest connection with n-alkanes of 3 metals - copper, cobalt and aluminum. They have significant correlations with the total amount of alkanes in general, and the first two - with 5-6 homologs directly from the 16 examined here. Such a relationship can be considered expected, given the high biogenicity of these elements, including the active exchange through the atmospheric channel <sup>11-12</sup>. Alkali and alkaline earth metals sodium, potassium, calcium, barium correlate with 1-2 n-alkanes. Soil aluminum and silicon, a number of other trace elements exhibit bonds with 1-3 n-alkanes.

In many of these cases, significant interest is caused by the fact that often non-unique metal-correlating homologs are close together, and thus can be the reference points for a completely different origin of the inorganic component, or indicate its significant catalytic and geochemical activity in the atmosphere or at the interface of geospheres <sup>13</sup>. It is obvious that further observation and investigation of the interaction of such seemingly heterogeneous components forming the atmospheric aerosol is necessary.

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#### REFERENCES

- [1] Gelencser, A., [Carbonaceous Aerosol], Springer, Dordrecht, 350 (2004).
- [2] Vehkamäki, H., [Classical Nucleation Theory in Multicomponent Systems], Springer-Verlag Berlin Heidelberg, 176 (2006).

- [3] Cappa, C., "Unexpected player in particle formation," *Nature* 533 (7604), 478-429 (2016).
- [4] Kirkby, J., Duplissy, J., Sengupta, K., Frege, C., Gordon, H., Williamson, Ch., Heinritzi, M., Simon, M., Chao Yan, Almeida, J., Tröstl, J., Nieminen, T., Ortega, I. K., Wagner, R., Adamov, A., Antonio Amorim, A., Bernhammer, A. K., Bianchi, F., Breitenlechner, M., Brilke, S., Chen, X., Craven, J., Dias, A., Ehrhart, S., Flagan, R. C., Franchin, A., Fuchs, C., Guida, R., Hakala, J., Hoyle, C. R., Jokinen, T., Junninen, H., Kangasluoma, J., Kim, J., Krapf, M., Kürten, A., Laaksonen, A., Lehtipalo, K., Makhmutov, V., Mathot, S., Molteni, U., Onnela, A., Peräkylä, O., Piel, F., Petäjä, T., Praplan, A. P., Pringle, K., Rap, A., Richards, N. A. D., Riipinen, I., Rissanen, M. P., Rondo, L., Sarnela, N., Schobesberger, S., Scott, C. E., Seinfeld, J. H., Sipilä, M., Steiner, G., Stozhkov, Yu., Stratmann, F., Tomé, A., Virtanen, A., Vogel, A. L., Wagner, A. C., Wagner, P. E., Weingartner, E., Wimmer, D., Winkler, P. M., Ye, P., Zhang, X., Hansel, A., Dommen, J., Donahue, N. M., Worsnop, D. R., Baltensperger, U., Kulmala, M., Carslaw, K. S. and Curtius, J., "Ion-induced nucleation of pure biogenic particles," *Nature* 533 (7604), 521-526 (2016).
- [5] Tröstl, J., Wayne, W. K., Gordon, H., Heinritzi, M., Chao Yan, Molteni, U., Ahlm, L., Frege, C., Bianchi, F., Wagner, R., Simon, M., Lehtipalo, K., Williamson, Ch., Craven, J. S., Duplissy, J., Adamov, A., Almeida, J., Bernhammer, A.-K., Breitenlechner, M., Brilke, S., Dias, A., Ehrhart, S., Flagan, R. C., Franchin, A., Fuchs, C., Guida, R., Gysel, M., Hansel, A., Hoyle, Ch. R., Jokinen, T., Junninen, H., Kangasluoma, J., Keskinen, H., Kim, J., Krapf, M., Kürten, A., Laaksonen, A., Lawler, M., Leiminger, M., Mathot, S., Möhler, O., Nieminen, T., Onnela, A., Petäjä, T., Piel, F. M., Miettinen, P., Rissanen, M. P., Rondo, L., Sarnela, N., Schobesberger, S., Sengupta, K., Sipilä, M., Smith, J. N., Steiner, G., Tomè, A., Virtanen, A., Wagner, A. C., Weingartner, E., Wimmer, D., Winkler, P. M., Ye, P., Carslaw, K. S., Curtius, J., Dommen, J., Kirkby, J., Kulmala, M., Riipinen, I., Worsnop, D. R., Donahue, N. M. and Baltensperger, U., "The role of low-volatility organic compounds in initial particle growth in the atmosphere," *Nature* 533 (7604), 527-531 (2016).
- [6] Bialek, J., Dall'Osto, M., Monahan, C., Beddows, D. and O'Dowd, C., "On the contribution of organics to the North East Atlantic aerosol number concentration," *Environ. Res. Lett.* 7 (044013), 7 (2012).
- [7] Ge, X., Wexler, A. S. and Clegg, S.L., "Atmospheric amines – Part 1. A review," *Atmos. Environ.* 45 (3), 524-545 (2011).
- [8] Virtanen, A., Joutsensaari, J., Koop, T., Kannisto, J., Yli-Pirila, P., Leskinen, J., Makela, J. M., Holopainen, J. K., Poschl, U., Kulmala, M., Worsnop, D. R. and Laaksonen, A., "An amorphous solid state of biogenic secondary organic aerosol particles," *Nature* 467 (7317), 824-827 (2010).
- [9] Antokhin, P. N., Arshinov, M. Yu., Belan, B. D., Davydov, D. K., Zhidovkin, E. V., Ivlev, G. A., Kozlov, A. V., Kozlov, V. S., Panchenko, M. V., Penner, I. E., Pestunov, D. A., Simonenkov, D. V., Tolmachev, G. N., Fofonov, A. V., Shamanaev, V. S. and Shmargunov, V. P., "Optik-É AN-30 aircraft laboratory: 20 years of environmental research," *J. Atmos. Ocean. Technol.* 29 (1), 64-75 (2012).
- [10] Voronetskaya, N. G., Pevneva, G. S., Golovko, A. K., Kozlov, A. S., Arshinov, M. Yu., Belan, B. D., Simonenkov, D. V. and Tolmachev, G. N., "Hydrocarbon composition of tropospheric aerosol in the south of West Siberia," *Atmospheric and oceanic optics* 27 (6), 547–557 (2014).
- [11] Dobrovolsky, V. V., [Basics of biogeochemistry], Vysshaya shkola, Moskva, 414 (1998).
- [12] Talovskaya, A. V., Yazikov, E. G., Shakhova, T. S. and Filimonenko, E.A., "Assessment of aerotechnogenic pollution: Case study in the vicinity of coal-fired and oil-fired local boiler houses in Tomsk region," *Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering* 327 (10), 116-130 (2016).
- [13] Tentyukov, M. P., "Income of metals to forest ecosystems with dry aerosol sinks: Influence of weather-forming processes and meteorological factors," *Russian Meteorology and Hydrology* 34 (5), 308-315 (2009).