Study of the disperse composition of the near-water aerosol over the White Sea in the end of summer, 2007

V.V. Pol'kin,[1] M.V. Panchenko,[1] I.V. Grishchenko,[2] V.B. Korobov,[2] A.P. Lisitsyn,[3] and V.P. Shevchenko[3]

[1]*V.E. Zuev Institute of Atmospheric Optics, Siberian Branch of Russian Academy of Sciences, Tomsk*
[2]*Arkhangelsk Center for Hydrometeorology and Environmental Monitoring with Regional Functions, Arkhangelsk*
[3]*P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow*

Received June 18, 2008

The spatial-temporal variability of the integral parameters (number density, mass concentration of submicron aerosol, mass concentration of crystal carbon) and the disperse composition (granulometry) of aerosol particles in the near-water layer of the marine atmosphere over the White Sea in August – September 2007 during the 53d cruise of the *Akademik Mstislav Keldysh* Research Vessel is analyzed. Many-year relations of the aerosol dispersity to meteorological parameters and synoptic conditions are studied.

Introduction

The planned character of investigations of the near-water aerosol of the White Sea is caused by the extreme importance of the channels of exchange and redistribution of the aerosol matter in northern polar latitudes of the Earth.[1,2] First, the White Sea has a specific geographical location among all Arctic seas of the Northern Hemisphere. The sea area is small and almost completely surrounded by land, which essentially intensifies the effect of land processes on the sea water. Second, several big industrial centers are situated just in the coastal zone, large volume of emissions and discharges of which come to environment. Third, there are essential climatic and oceanological differences in natural conditions of the White Sea from natural conditions of other seas of the Arctic Ocean because of its more southern location.

The spatial-temporal variability of aerosol particle parameters of the near-water layer of the White Sea, connections of the aerosol dispersity with meteorological parameters and synoptic situations have been studied during several years.[3–6] As continuation of these works, the microstructure, number concentration, and chemical composition of aerosol were investigated in different regions of the White Sea in August and September, 2007 in the 53d cruise of RV *Akademik Mstislav Keldysh* in the framework of the project "The White Sea system" and the project No. 232 of International polar year 2007/08 "Study of eolic and ice transfer and fluxes of substances (including ecotoxicants) in Arctic".[7,8]

The comparison of parameters of the near-water aerosol in different years and in different regions of the White Sea under different meteorological and synoptic conditions enables one to obtain complete imagination on the variety of processes occurring in the region under study.

Instrumentation and techniques

The aerosol parameters were studied along the route of RV *Akademik Mstislav Keldysh* (Fig. 1) by means of the automated mobile aerosol complex (aerosol station),[9] situated in meteorlogical laboratory starboard of the vessel at a height of about 16 m above the water surface in the zone of minimal influence of the local aerosol sources (exhaust of the vessel, ventilation shaft of the engine-room, etc.). The complex included the modified FAN-type nephelometer of angular scattering, automated photoelectric particle counter (PPC) AZ-5 and the aethalometer (absorption photometer). Measurements were carried out round-the-clock every 0.5 hour.

The dispersion composition (granulometry) and the aerosol number density N_a (cm^{-3}) was measured by means of the automated PPC in 256 size ranges from 0.4 to 10 μm in diameter. The FAN nephelometer measured the angular scattering coefficient $\mu(45°)$ (km^{-1} · sr^{-1}) at an angle of 45° and a wavelength of 0.52 μm. The values of the mass concentration of submicron aerosol M_a (μg · m^{-3}) were determined using the formula from the empirical model IAP RAS.[10] The aethalometer was used in the real-time measurements of the mass concentration of black carbon M_C (μg · m^{-3}) in air (the operational principle of the device is similar to that described in Ref. 11).

0235-6880/08/10 725-05 $02.00

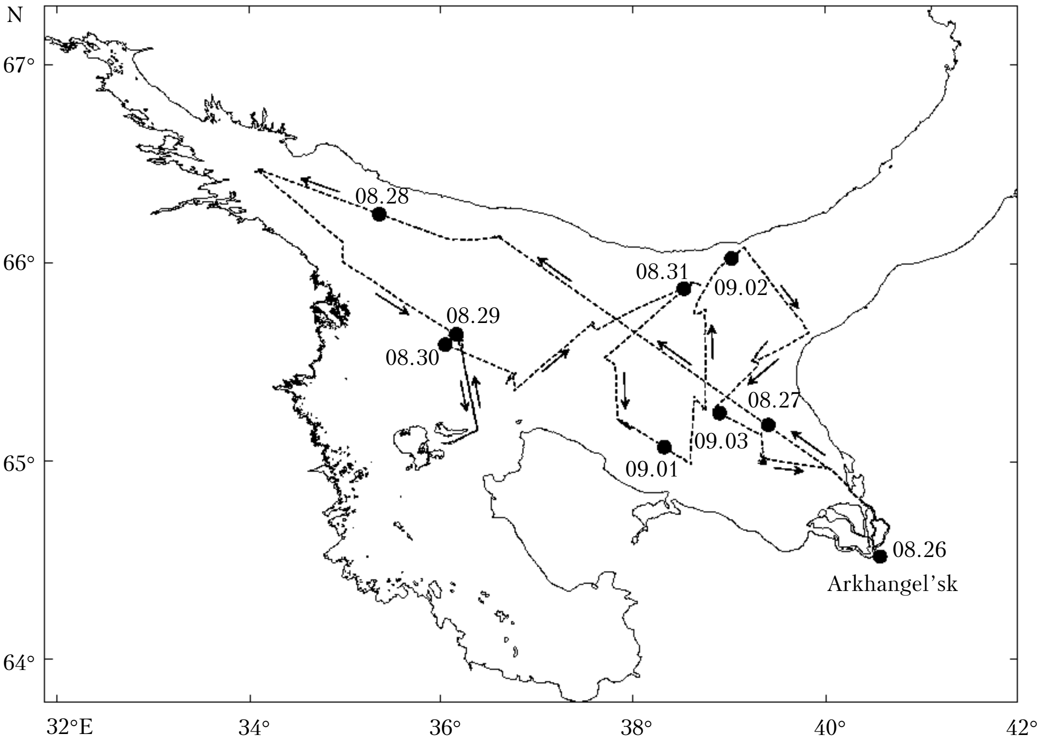

Fig. 1. Route of the 53d cruise of RV *Akademik Mstislav Keldysh* in the White Sea. Black circles denote the position of the vessel at the beginning of each day from August 28 to September 3, 2007.

Synoptic conditions during investigations

Synoptic conditions over water area of the White Sea between August 25 and September 3, 2007 were as follows.

August 25. Water area of the White Sea was under influence of intermediate ridge, a weak increase of pressure and weak north-west wind were observed. At the end of the day, the front part of the cyclone (942 mbar in the center) with the center at the north of Sweden appeared. The cyclone moved to the east with a velocity of 60–70 km/h. The pressure decreased by 3.5 mbar per 3 hours. A south-west wind of 7–12 m/s was observed.

August 26. The cyclone center moved to Mezen Bay and then to south-east. The pressure above water surface of the White Sea was increasing by 1.3–2.4 mbar per 3 hours. South-west and west winds were related with this cyclone rear, and a mean velocity of 7–12 m/s was characteristic for north and north-east winds in Kandalaksha Bay and Mouth (the narrowing between Dvine and Mezen Bays); blasts in Mouth reached 17 m/s. The weather at the height was affected by trough of the cyclone situated above Kara Sea, which caused west and north-west winds of 10–15 m/s in a layer of 1.5–5 km.

August 27. The water area of the White sea was affected by the north-west periphery of the cyclone long trough above Kara Sea, traced up to 500 mbar. At the second half of the day, a local cyclone appeared in the region of Arkhangelsk, which caused some intensification of the north and north-east winds at the sea west with blasts up to 16–17 m/s. The pressure increase was 1.6–2.5 mbar per 3 hours.

August 28. The core of the anticyclone from Kola peninsula came to the area of the White Sea. Then the core went to the east. A weak east wind was observed over the sea. At the height, as before, the trough of Kara cyclone with weak north-west and west winds was observed.

August 29. The north-eastern periphery of the cyclone with the center in the region of Saint Petersburg affected the sea. Then the cyclone moved to the north-east. It caused a decrease of pressure by 2.9 mbar per 3 hours and the north-east wind with a mean velocity of 10–12 m/s with blasts up to 15–16 m/s. Analogous situation was observed in the middle troposphere: the cyclone appeared over Karelia, the north-east periphery of which caused south-east and east winds of 5–10 m/s over water area of the White Sea.

August 30. The cyclone center was situated over Dvina Bay at a pressure of 988 mbar, the pressure decrease was 3.3 mbar per 3 hours. North and north-west winds with a mean velocity of 10–12 m/s were observed over the water area of the White Sea, the wind blasts in Kandalaksha Bay reached 15–16 m/s. At the second half of the day, as the cyclone moved to the north-east, the pressure increase by 1.7 mbar per 3 hours was observed over the sea. The wind weakened to 7–10 m/s.

August 31. The water area of the White Sea was under the influence of the cyclone rare with the center over Kanin Nos both at a height and near the ground.

A pressure increase by 1.0–1.6 mbar per 3 hours, as well as north-west and west winds up to 10–12 m/s were observed.

September 1–2. Meteorological conditions were determined by the trough of the cyclone over the Barents Sea, in which weak winds of variable directions were observed.

September 3. The eastern periphery of the vast cyclone over the west of Norway affected water area of the White Sea, in the trough of which the local cyclone appeared in the daytime over Dvina Bay in Karelia. South-east and east winds prevailed.

Thus, the cyclonic circulation was observed during the whole period over water area of the White Sea with a short-time intrusion of the high pressure core from Kola Peninsula.

Analysis of experimental data

The general temporal behavior of the main measured integral parameters and temporal variations of near-water values of meteorological parameters are shown in Fig. 2.

Mean values of meteorological parameters in the total data array are the following: $V = (9.2 \pm 3.5)$ m/s, $RH = (73.0 \pm 8.1)$ %, $T = (10.0 \pm 2.1)$°C. Of interest are enhanced values of the main integral parameters in the region of port Arkhangelsk during arrival and departure of vessels. These data are marked by light circles in Fig. 2*a*. Mean values of parameters at those moments were as follows: $M_a = (6.9 \pm 6.0)\ \mu g \cdot m^{-3}$, $N_a = (4.0 \pm 4.8)\ cm^{-3}$, $M_C = (0.36 \pm 0.47)\ \mu g \cdot m^{-3}$. Dark circles mark measurements carried out directly in the sea. Mean values during this period were $M_a = (2.1 \pm 1.1)\ \mu g \cdot m^{-3}$, $N_a = (4.9 \pm 2.8)\ cm^{-3}$, $M_C = (0.043 \pm 0.09)\ \mu g \cdot m^{-3}$. It is seen that the mean values and rms deviations of the mass concentrations of black carbon and aerosol in the region of Arkhangelsk are several times greater than in the open sea. The inverse situation is observed for the mean values of the number concentration, although the behavior of the root mean square deviation (rmsd) of the number concentration is analogous to the behaviors of rmsd of other parameters.

The volume size distributions $\Delta V_i/\Delta R_i$, where $\Delta V_i = (4/3)\pi R_i^3 \Delta N_i$ are the volumes of particles in the ith subrange of measurement (R_i is the mean particle radius and ΔN_i is the concentration of particles in the ith subrange), were calculated for analysis of the behavior of the particle size distribution function. The results of calculations are shown in Fig. 3.

It is seen that during departure of the vessel from Arkhangelsk (August 26, 2007) the particle volume size distribution function has minimal values, especially for coarse fraction ($R > 1\ \mu m$). The roughness of the sea surface is minimal. A sharp increase of wind velocity on August 26, which began at 17.00 and finished at 18.30 did not affect the values of the distribution function in the coarse-dispersion range, because the wind velocity to the beginning of measurements at 19.30 became less than 10 m/s (Fig. 2*b*). At the vessel arrival to Arkhangelsk on September 3, 2007, the values of the distribution function were maximal both in submicron and coarse size ranges. The noted peculiarities of the behavior of the integral parameters, as distinct from M_a, N_a, and the distribution function, are explained, most likely, by the presence of high concentrations of finely dispersed particles of the anthropogenic origin with sizes less than the lower boundary of sensitivity of PPC (0.4 μm) in the region of Arkhangelsk that day.

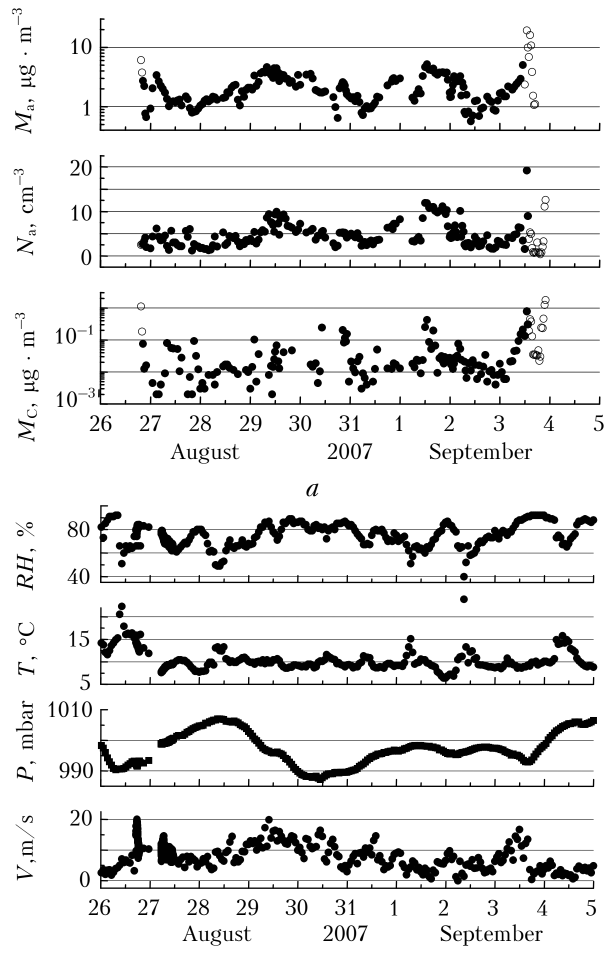

Fig. 2. Distributions of the parameters, measured onboard RV *Akademik Mstislav Keldysh*: M_a is the mass concentration of submicron aerosol; N_a is the number concentration of particles with diameters more than 0.4 μm; M_C is the mass concentration of black carbon (*a*); RH is the relative humidity of air, T is the temperature, P is the pressure, V is the wind velocity (*b*).

The cyclonic circulation, accompanied by passing fronts in the open sea during the measurements, caused the increase of the wind velocity and sea roughness, as well as intensified the generation of particles of both coarse and fine size ranges from sea surface (bubble mechanism, break of splashes and foam of sea water with subsequent draining). It was observed the most clearly on August 29 and September 1 (see Fig. 2*a*). The following values were recorded: $M_a^{max} = 5.2$ μg · m^{-3}, $N_a^{max} = 11.9$ cm^{-3} (September 1). At the same time, the behavior of M_C was practically neutral, although with big variance.

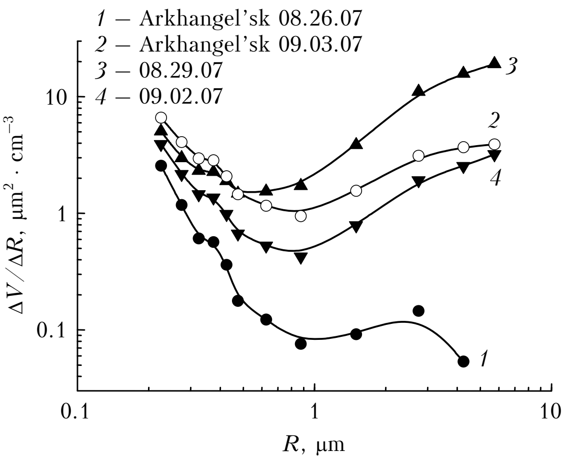

Fig. 3. Aerosol particle volume size distribution in situations with maximal (August 29, 2007) and minimal (September 2, 2007) wind velocities, as well as during departure and arrival of the vessel to Arkhangelsk.

August 29 and September 2, 2007 were the most contrast in the wind velocity. Mean values of the wind velocity were, respectively, 13.5 and 4.8 m/s. The values of basic measured parameters were as follows: for August 29: $M_a = (3.3 \pm 0.7)$ μg · m^{-3}, $N_a = (6.7 \pm 2.0)$ cm^{-3}, $M_C = (0.03 \pm 0.03)$ μg · m^{-3}; and for September 2: $M_a = (1.57 \pm 0.8)$ μg · m^{-3}, $N_a = (3.9 \pm 1.9)$ cm^{-3}, $M_C = (0.02 \pm 0.002)$ μg · m^{-3}. Mean particle volume size distribution were calculated for these days (see Fig. 3).

The high wind velocity leads to the increase of the volumes of submicron, and especially coarse particles. The volumes of submicron particles increased by 1.2–2 times, while the volumes of coarse particles increased by 3–6 times.

Of interest is the comparison of the annual mean aerosol particle volume size distributions obtained during several years (2003–2007) (Fig. 4).

All data were obtained in different years in the second half of August. Mean values of the temperature *T* (°C) and wind velocity *V* (m/s) for each year are additionally shown in Fig. 4, which illustrates significant qualitative differences in distributions of different years.

The peculiarity of distributions in 2004–2006 is high values throughout the size spectrum. Sharp decrease of values in submicron radius range between 0.2 and 1 μm was observed in 2003 and 2007. The greatest increase of the volume distribution was observed in the range of radii exceeding 1 μm in 2003, and the smallest one in 2003.

Approximation of the obtained distributions was based on the idea of two fractions (submicron and coarse) in the form of two lognormal distributions. Submicron range was approximated by distributions with the variance between 0.6 (2003) and 1.0 (2005, 2006) and modal radii between 0.01 (2006, 2007) and 0.1 μm (2004). Coarse part of distributions was approximated by wider distributions with the variance from 1.0 (2004, 2005, 2007) to 1.2 (2003, 2006) and modal radii from 1–3 (2004–2006) to 6 μm in 2003 and 10 μm in 2007.

	2003 (1)	2004 (2)	2005 (3)	2006 (4)	2007 (5)
V, m/s	6.0	8.1	10.0	4.7	9.2
T, °C	13.0	11.0	15.4	12.9	10.0

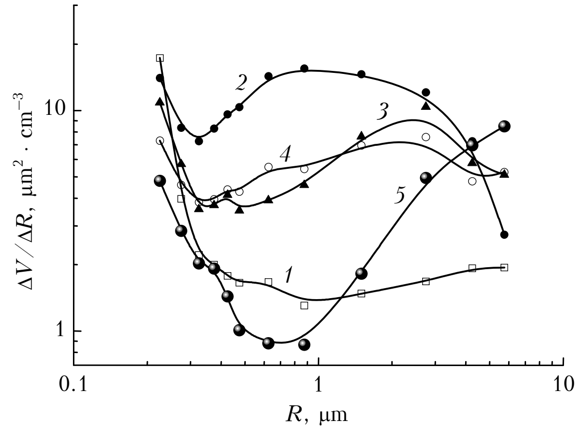

Fig. 4. Aerosol particle volume size distribution in summer of different years.

Note that data of 2004–2006 include measurements at big relative humidity of air and the presence of fogs, therefore, the distributions for these years in radius range 0.4–1 μm are high. It is the size range, where particles grow during fogs.

High values of the distribution function for these years in the coarse range are caused by the presence of big wind velocities (the exception is 2006). Fogs almost were not observed during the experiments in 2003 and 2007, and the atmospheric transparency was quite high, the mean wind velocity in 2003 was only 6 m/s, and in 2007 – 9 m/s. Therefore, the values of the distribution functions in radius range 0.4–1 μm in 2003 and 2007 were low, while in the coarse range in 2007 the values were high.

Conclusion

Analysis of the temporal behavior of the integral parameters and distribution functions of the near-water marine aerosol of the White Sea have revealed a good sensitivity of these parameters to synoptic and meteorological conditions and to the position of the measurements relative to continental and anthropogenic aerosol sources.

As the wind velocity increased to 10 m/s and more, the values of the integral parameters and the aerosol particle size distribution function increased. The increase of particle volumes occurred mainly in the range of coarse radii (more than 1 μm).

The increase of values of integral parameters and the distribution function in the regions close to continental and industrial aerosol sources was provided for mainly by increase of volumes of the particles of submicron range with the radii less than 0.2 μm.

The high relative humidity of air and the presence of fogs resulted in the increase of volumes of particles of intermediate radius range 0.4–1 μm.

Acknowledgements

Authors would like to thank the crew of RV *Akademik Mstislav Keldysh* for the help during the expedition.

The work was supported in part by Russian Foundation for Basic Research (Grant No. 06–05–64393), the Grant for Support Leading Scientific Schools NSh-361.2008.5, Programs of basic researches of Presidium RAS No. 16, part 2 and No. 17 (Projects 4.4 and 17.1), Project "Nanoparticles in inner and external spheres of the Earth) and O. Schmidt Russian-German laboratory.

References

1. A.P. Lisitsyn, in: *Urgent Problems of Oceanology* (Nauka, Moscow, 2003), pp. 503–556.
2. V.P. Shevchenko, *Effect of Aerosols on Environment and Marine Deposition Accumulation in Arctic* (Nauka, Moscow, 2006), 226 pp.
3. V.V. Pol'kin, Vas.V. Pol'kin, M.V. Panchenko, V.S. Kozlov, A.P. Lisitsyn, and V.P. Shevchenko, in: *Abstract of Reports at XV International School of Marine Geology "Geology of seas and oceans", 17–21 of November, 2003* (GEOS, Moscow, 2003), pp. 112–113.
4. V.V. Pol'kin, L.P. Golobokova, V.S. Kozlov, V.B. Korobov, A.P. Lisitsyn, M.V. Panchenko, M.A. Peskova, T.V. Khodzher, and V.P. Shevchenko, Atmos. Oceanic Opt. **17**, Nos. 5–6, 330–338 (2004).
5. V.V. Pol'kin, L.P. Golobokova, T.V. Pogodaeva, V.S. Kozlov, V.B. Korobov, A.P. Lisitsyn, M.V. Panchenko, M.A. Peskova, T.V. Khodzher, and V.P. Shevchenko, in: *Basic Research of Oceans and Seas* (Nauka, Moscow, 2006), pp. 413–439.
6. V.S. Kozlov, A.B. Tikhomirov, V.V. Pol'kin, M.V. Panchenko, A.P. Lisitsyn, and V.P. Shevchenko, in: *Abstracts of Reports at XIV Int. Symp. "Atmospheric and Ocean Optics. Atmospheric Physics"* (IAO SB RAS, Tomsk, 2007), p. 127.
7. V.V. Pol'kin, L.P. Golobokova, M.V. Panchenko, and V.S. Kozlov, in: *Abstract of Reports at XIV Workshop "Siberian Aerosols"* (IAO SB RAS, Tomsk, 2007), p. 11.
8. V.P. Shevchenko, A.P. Lisitsyn, A.A. Vinogradova, N.V. Goryunova, N.S. Zamber, V.B. Korobov, K.P. Koutsenogii, I.A. Nemirovskaya, A.N. Novigatskii, M.V. Panchenko, S.A. Pozdnyakov, and V.T. Sokolov, in: *Abstracts of Reports at Scientific Conference "Russia in IPY – First Results", Sochi, October 3–9, 2007* (Sochi, 2007), pp. 103–104.
9. V.S. Kozlov, M.V. Panchenko, V.V. Pol'kin, and V.P. Shmargunov, in: *Abstract of Reports at XIII Workshop "Siberian Aerosols"* (IAO SB RAS, Tomsk, 2006), p. 58.
10. G.I. Gorchakov, A.S. Emilenko, and M.A. Sviridenkov, Izv. Akad. Nauk SSSR. Fiz. Atmos. i Okeana **17**, No. 1, 39–49 (1981).
11. A.D.A. Hansen, H. Rosen, and T. Novakov, Sci. Total Environ. **36**, No. 1, 191–196 (1984).