UDC 550.462 + 582.29

DOI: 10.15372/KhUR20160402

Atmospheric Black Carbon over the North Atlantic and the Russian Arctic Seas in Summer–Autumn Time

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Abstract

The distribution of atmospheric black carbon (BC) in the marine boundary layer of the North Atlantic and Baltic, North, Norwegian, Barents, White, Kara and Laptev Seas was studied in research cruises with the RV "Akademik Mstislav Keldysh" during July 23 to October 24, 2015. Air was filtered through Hahnemuhle Fineart Quarz-Microfibre filters. The mass of BC on the filter was determined by the measurement of the attenuation of a beam of light transmitted through the filter. Source areas were estimated by backwards trajectories of air masses calculated using NOAA's HYSPLIT model (http://www.arl.noaa.gov/ready.html) and FLEXPART model (http://www.flexpart.eu). During some parts of the cruises, air masses arrived from background areas of high latitudes, and the measured BC concentrations were low. Over other parts of the cruises, air masses arrived from industrially developed areas with strong BC sources, and this led to substantially enhanced measured BC concentrations. Model-supported analyses are currently performed to use the measurement data for constraining the emission strength in these areas.

Key words: black carbon, marine boundary layer, North Atlantic, Arctic, backward trajectories, emission strength

INTRODUCTION

Black carbon (BC) is a distinct type of carbonaceous material that is primarily produced by incomplete combustion of fossil fuels (coal and diesel), biofuels, as well as biomass burning. It is directly emitted to the atmosphere, and presents a unique combination of physical properties [1]. BC is the most efficient atmospheric light-absorbing aerosol species and it could have a potential impact on the Arctic climate [1–6]. However, measurement data of the distribution of BC in the atmosphere over the Russian Arctic Seas is scarce [7–17].

MATERIALS AND METHODS

We present measurements of atmospheric BC in the marine boundary layer of the North Atlantic and Baltic, North, Norwegian, Barents, White, Kara and Laptev Seas from the 62nd, 63rd and 64th research cruises of the RV "Akademik Mstislav Keldysh" from July 23 to October 24, 2015. The route of the vessel is shown at Figs. 1 and 2. During the cruises air was filtered through Hahnemuhle Fineart Quarz-Microfibre filters at 10 m above sea level. The mass of BC on the filter was determined by measuring the attenuation of a light-

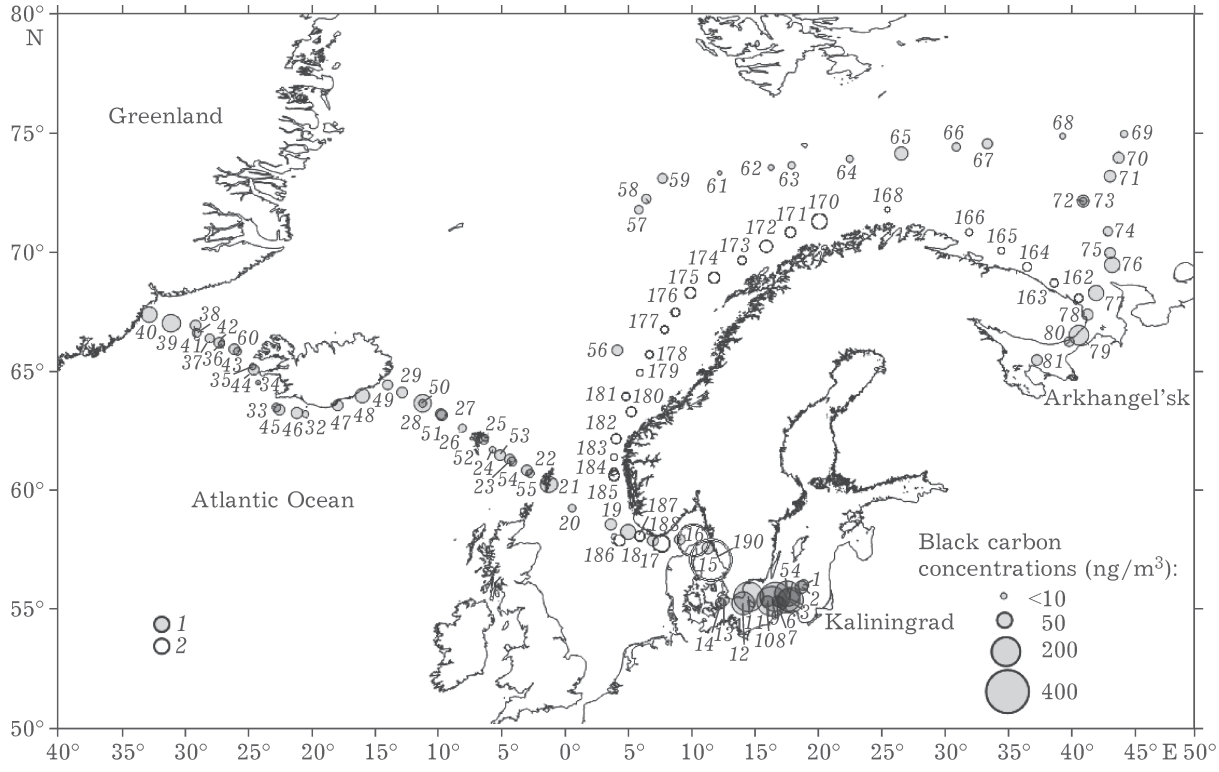

Fig. 1. Distribution of black carbon in marine boundary layer during the 62nd cruise (23.07–20.08.2015) (*1*) and the 64th cruise (17.10–24.10.2015) of the RV "Akademik Mstislav Keldysh" (*2*). Sample numbers are indicated near circles.

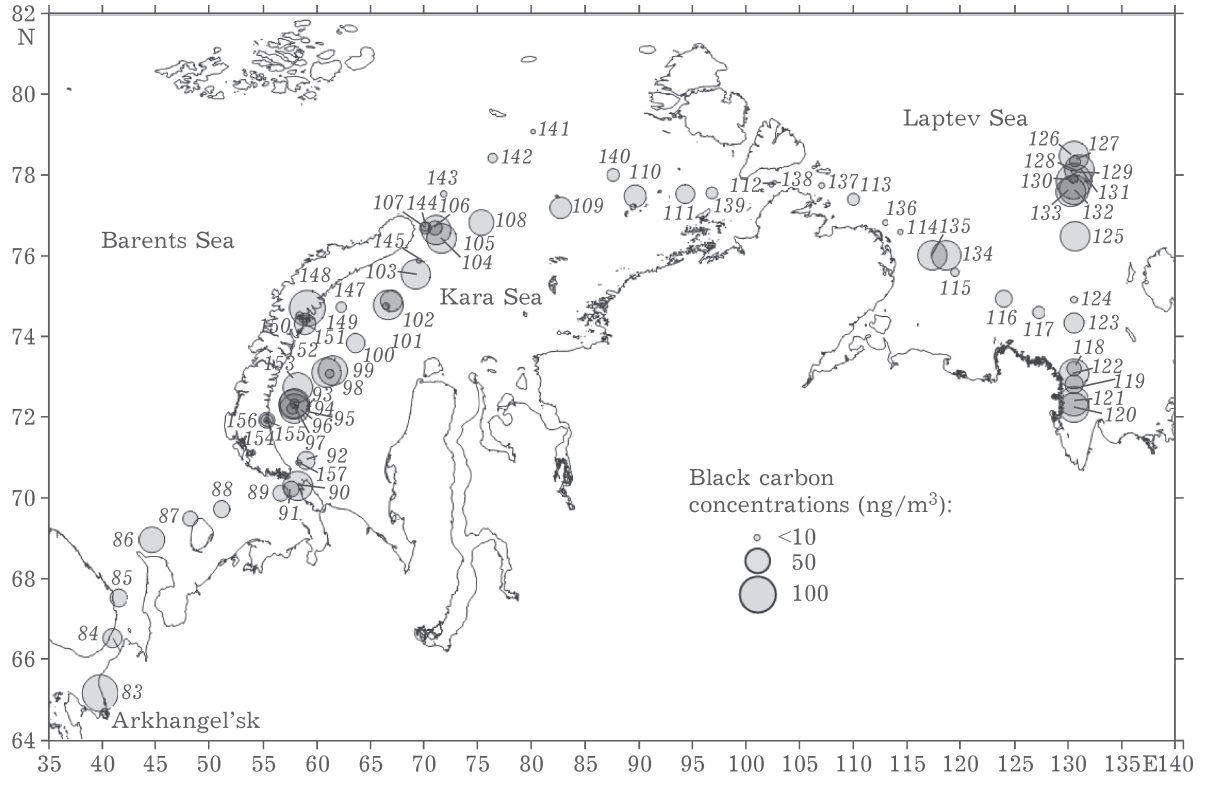

Fig. 2. Distribution of black carbon in marine boundary layer during the 63rd cruise of the RV "Akademik Mstislav Keldysh" (26.08–06.10.2015). Sample numbers are indicated near circles.

beam transmitted through the filter. Source areas were estimated by backwards trajectories of air masses calculated using NOAA's HYSPLIT model (http://www.arl.noaa.gov/ready.html) [18] and FLEXPART model [19, 20].

RESULTS AND DISCUSSION

During the 62nd cruise of the RV "Akademik Mstislav Keldysh" (23.07–20.08.2015) the BC concentrations (see Fig. 1) varied from <10 to 261 ng/m^3 (81 ng/m^3 on average, n = 61). The highest BC concentrations were registered in the Baltic Sea in the area of intensive shipping and situated close to areas with dense population (up to 258 ng/m^3 in sample *8* and 261 ng/m^3 in sample *11*). BC concentrations in the Baltic Sea in June of 2011 have been reported to be 280 ng/m^3 on average [21]. Emission sensitivities calculated with FLEXPART showed that these high concentrations are probably attributed to anthropogenic BC originating from Northern European countries, rather than biomass burning in Eurasia. Relatively high BC concentration was near the southeastern Greenland in the area of shipping (139 ng/m^3 in sample *39* and 118 ng/m^3 in sample *40*). Ships contribute significantly to global climate change and health impacts through emission of greenhouse gases and other pollutants, including BC [22, 23]. Arctic impacts from regional shipping may be compared with long-range transport of larger emissions sources from lower latitude biomass and fossil fuel combustion [24].

The lowest BC concentrations (<50 ng/m^3 and in some samples <10 ng/m^3) were in the North Atlantic and the Barents Sea when air masses arrived from the Arctic (according to backward trajectories analysis [18]).

During the 63rd cruise of the RV "Akademik Mstislav Keldysh" (26.08–06.10.2015) the BC concentrations (see Fig. 2) varied from <10 to 116 ng/m^3 (34 ng/m^3 on average, n = 54). The average value in this expedition was lower than in previous expeditions in this region (Fig. 3).

The highest BC concentrations were found in the White Sea in vicinity of Arkhangelsk city (116 ng/m^3 in sample *83*) and in the Laptev Sea in vicinity of Tiksi port (112 ng/m^3 in sample *120*). Our FLEXPART backward runs associated with ECLIPSE emission inventory [25] predicted a surface BC concentration for Tiksi port of 121.3 ng/m^3. 49.7 ng/m^3 are attributed to anthropogenic emission and the rest to biomass burning ones. Nevertheless, the origin of

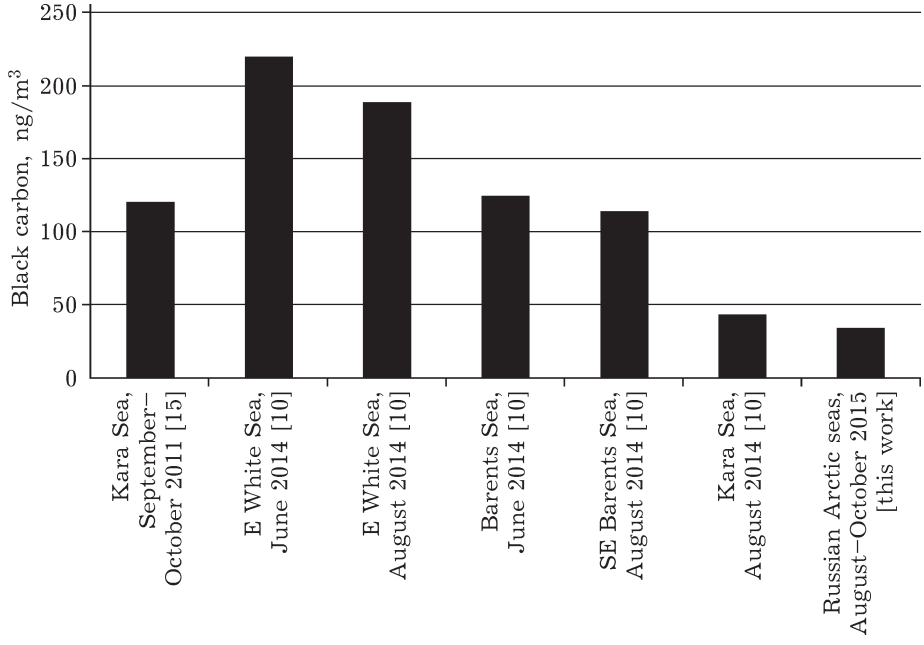

Fig. 3. BC concentrations in atmospheric boundary layer in the Russian Arctic seas in summer-autumn period, ng/m^3.

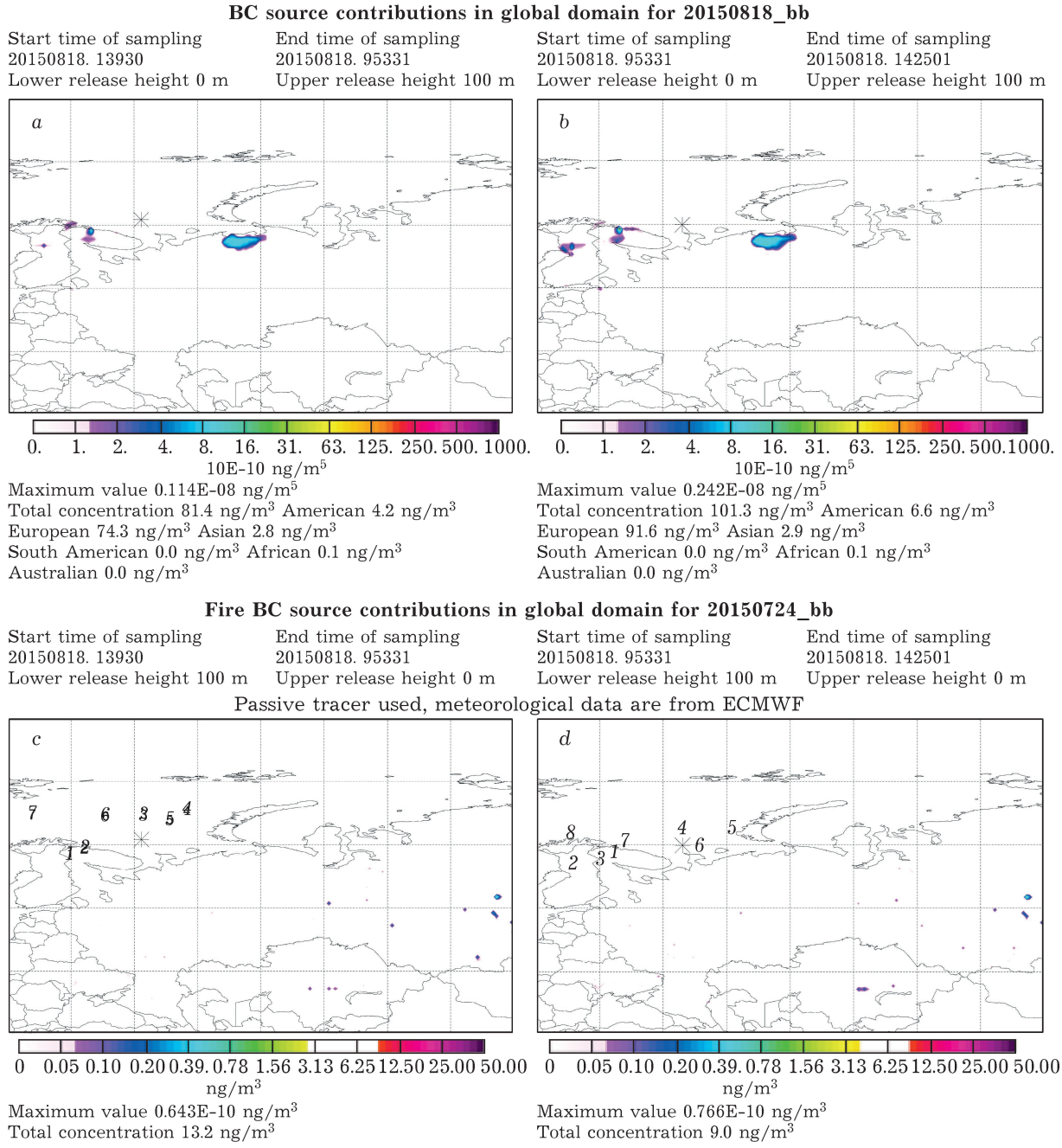

Fig. 4. BC contribution on surface concentrations from various continents and sources for two different days when samples *109* and *110* were collected onboard the RV "Akademik Mstislav Keldysh" in the Kara Sea. Figure 4, *a* and *b* depict contribution from anthropogenic sources from various continents and Fig. 4, *c* and *d* from fires recorded from NASA's MODIS satellites.

BC was rather from local sources. The lowest values (<10 ng/m^3) were observed in northern Kara Sea (samples *112*, *141*, *142*) and in the Laptev Sea (samples *114*, *124*, *136*, *137*) when air masses arrived from Central Arctic.

BC concentrations were relatively higher in the Kara Sea, as well (samples *108–111*), collected when air masses arrived from the northwestern Siberia (area of active gas flaring and industry [26]). Earlier the influence of BC from

Siberian gas flaring was described for the Kara Sea aerosols [15]. This is confirmed by FLEXPART, which estimated a BC concentration of 94.6 and 110 ng/m^3 in the area of samples *109* and *110*, of which 81.4 and 101.3 ng/m^3, respectively, are attributed to gas flaring (characteristic hot-spot in Fig. 4, *a* and *b*). For both samples *109* and *110* the influence of forest fires source of visible in the southeastern Siberia (see Fig. 4, *c* and *d*). Siberian forest fires in some periods are important source of BC in the Arctic [27, 28].

During the 64th cruise of the RV "Akademik Mstislav Keldysh" (17.10–24.10.2015) the BC concentrations (see Fig. 1) varied from <10 to 483 ng/m^3 (84 ng/m^3 on average, n = 28). The highest BC concentrations were registered in the western Baltic Sea in the area of intensive shipping (355 ng/m^3 in sample *189* and 483 ng/m^3 in sample *190*). The lowest BC concentrations (from <10 ng/m^3 in sample *168* to 50 ng/m^3 in sample *164*) were in the southern Barents Sea when air masses arrived from the North Atlantic (according to backward trajectories analysis [18]).

CONCLUSION

During some parts of the cruises, air masses arrived from background areas of high latitudes, and the measured BC concentrations were low. During other parts of the cruises, air masses arrived from industrially developed areas with strong BC sources, and this led to substantially enhanced measured BC concentrations. Model-supported analyses are currently performed with the use the measurement data for constraining the emission strength in these areas.

Acknowledgements

The authors are thankful to the crew of the RV "Akademik Mstislav Keldysh" for help in expeditions. The authors greatly acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport model, READY website (http://www.arl.noaa.gov/ready.html) and authors of FLEXPART model (http://www.flexpart.eu).

Our studies were financially supported by the Russian Fund for Fundamental Research (projects 14-05-93089 and 14-05-00059), Program No. 32 of Fundamental Research of the Presidium of Russian Academy of Sciences and the Research Council of Norway (SLICFONIA project).

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UDC 550.462 + 582.29

DOI: 10.15372/KhUR20160402

Атмосферный черный углерод над Северной Атлантикой и морями Российской Арктики в летне-осеннее время

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Аннотация

Распределение атмосферного черного углерода в приводном слое воздуха над Северной Атлантикой и Балтийским, Северным, Норвежским, Баренцевым, Белым и Карским морями и морем Лаптевых исследовано в ходе научных рейсов на борту НИС “Академик Мстислав Келдыш” с 23 июля по 24 октября 2015 г. Воздух фильтровали через высококачественные кварцевые микроволокнистые фильтры Hahnemuhle. Массу черного углерода на фильтрах определяли, измеряя ослабление луча света, прошедшего через фильтр. Районы-источники черного углерода оценивали с помощью модели HYSPLIT расчета обратных траекторий переноса воздушных масс, разработанной Национальной администраций США по изучению океана и атмосферы (http://www.arl.noaa.gov/ready.html) и модели FLEXPART (http://www.flexpart.eu). При прохождении ряда участков маршрута судна воздушные массы поступали из фоновых высокоширотных районов, поэтому измеренные концентрации черного углерода были низкими. При прохождении других участков воздушные массы поступали из промышленно развитых районов с сильными его источниками, поэтому концентрации черного углерода значительно выше. Полученные данные о концентрациях черного углерода использованы для верификации данных о его эмиссии в этих районах.

Ключевые слова: черный углерод, приводный слой морской атмосферы, Северная Атлантика, Арктика, обратные траектории, мощность эмиссии