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Black Carbon Emissions from Wildfires on Forest Lands of the Russian Federation in 2007–2012

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Abstract—Presented is the method of computational monitoring of black carbon emissions due to wildfires. The computation is carried out for the territory of Russia for the period of 2007–2012. Given is the distribution of black carbon emissions according to fire types and regions. The mean value of black carbon emission due to wildfires for the period under consideration amounted to 81.9 37.2 10^3 t/year and interannual variations are from 53.8 10^3 t in 2011 to 143.5 10^3 t in 2008. The mean value of black carbon emission in the forests is 25.0 3.7 kg/ha for crown fires, 24.0 0.1 kg/ha for underground fires, 10.2 1.2 kg/ha for ground fires, and 4.1 0.3 kg/ha for fires in non-forested areas.

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INTRODUCTION

Black carbon is "…a solid form of mostly pure carbon that absorbs solar radiation (light) at all wavelengths" [19]. It is the most effective form of particulate matter absorbing the solar energy and a major component of soot that contains organic carbon and other impurities in addition to the black carbon. The most part of black carbon emissions are due to the incomplete combustion of fossil fuels, biofuels, and biomass. Its atmospheric lifetime is short, from days to weeks, because particles are easily washed out with precipitation. Aerosol particles containing black carbon influence the climate: they absorb the solar energy, emit the infrared (heat) radiation, and change the albedo after falling to the Earth surface that results in its additional heating. These effects are the most crucial in the zones covered by snow and ice (in polar and mountain regions) where the melting goes faster. The estimated net radiation disturbing effects of black carbon particles occur due to the direct absorption of solar radiation, interaction with clouds, and their heating as well as due to the variations of the albedo of snow and ice. These effects vary from 0.64 W/m^2 [14] to 1.1 (0.17–2.1) W/m^2 [12] that corresponds to the surface heating which is by 2–4 times larger than in the case of carbon dioxide (CO_2) impact.

Black carbon is formed not only due to wildfires but also in the process of the combustion of organic compounds, for example, as a result of the operation of diesel generators, heating of premises with coal, firewood, and black oil, and cooking in ovens and stoves. In some countries including Russia, one of the most essential sources of black carbon emission to the atmosphere is forest fires [11, 15, 16, 19]. Both the greenhouse agent (black carbon) and other compounds (in particular, organic carbon) are emitted to the atmosphere as a result of forest fires and exert cooling influence on the atmosphere. These interrelated and oppositely directed effects should be taken into account for working out measures aimed at the reduction of emission of greenhouse gases due to biomass combustion.

The problem of black carbon effects on the climate change has recently attracted more attention in the scientific community and at the intergovernmental level. For example, in 2012 several countries formed the coalition that studies this problem and proposes practical measures for the reduction of black carbon emissions (Climate and Clean Air Coalition, CCAC). The sphere of interest of the coalition also includes other short-lived climate agents: methane, tropospheric ozone, and hydrofluorocarbons. Unlike long-lived greenhouse gases (their lifetime is 100 years and more), short-lived greenhouse agents are not able to circulate for a long time in the atmosphere–ocean–land ecosystems. Therefore, the reduction of the volume of their emissions may affect their content in the atmosphere rather quickly: in 10 years and less. It is supposed that measures on the reduction of emissions of short-lived greenhouse agents along with the control over CO_2 emissions can decrease the anthropogenic rise of global temperature by 0.5°C by 2050 [18].

Methane and hydrofluorocarbons are the greenhouse gases to be controlled according to the United Nations Framework Convention on Climate Change (UNFCCC), and their emissions are assessed every year in the National Greenhouse Gas Inventories of greenhouse gases not regulated under the Montreal Protocol [6, 7]. Tropospheric ozone is the secondary product of greenhouse gases regulated by UNFCCC. Unlike the above, black carbon is currently not an object of monitoring (both for emissions and for the presence in the atmosphere and fallouts to the surface).

According to the data available in literature, the emissions of black carbon from forest fires in Russia make up from 40 to 56% of the total emission of black carbon at the local level (biomass, coal, wood, etc.). Grass fires, industry, and transport contribute 10% each [13, 19]. The contribution of Russia at the global scale is estimated at 4–5% of the total emission of black carbon [13, 19]. The contribution of Russia to the global emissions of black carbon caused by wildfires makes up 12–13% [13, 19]. However, the existing estimates of black carbon emissions are highly uncertain and are characterized by significant interannual variability. For example, according to the Fourth-generation Global Fire Emissions Database [17], black carbon emissions from the boreal forests of Russia vary within a wide range: from 28×10^3 t in 2004 to 263×10^3 t in 2012. In view of this, there is an urgent need in assessing black carbon emissions and in creating the system of yearly monitoring (both computational and experimental). It is necessary to ensure the comparability of the results with the National Greenhouse Gas Inventories [6, 7] and provide methodological comparability (the use of the method of computational monitoring) and the agreement in the geographic coverage of the territory and initial data.

The objective of the present research was to assess of black carbon emissions from fires on the forest lands of the Russian Federation for the period of 2007–2012 using the method of computational monitoring [3].

DATA AND METHODS

To assess black carbon emissions, the data were used of the Informational Remote monitoring System of the Federal Forestry Agency of the Russian Federation (Rosleskhoz) [4] on the areas of forest lands damaged by fires in 2007–2012 in the separate regions of the Russian Federation. The information is used on the total area damaged by fire and on the area of forest-covered lands damaged by fire. Separately the areas of burnt forests were taken into account where more than 75% of forest stand was damaged. The areas were singled out where the fires of three types were observed, namely, ground fires; crown fires; fires on the lands not covered by forest vegetation (burnt forests, fellig areas, failed areas, and dead stands) and on the non-forested lands (cutting, glades, etc.). The areas of underground fires are not registered due to their small size and are referred to the burnt forests where stands were completely destructed by fire. The data on the area of underground fires were taken from the Rosleskhoz reports. Thus, the used data on the fire area include the data of remote sensing and aerial visual survey as well as the data of the ground-based exploration. The total accuracy of the data on the fire area estimated by Aerial Forest Fire Center is ±30%.

To compute the fuel available for combustion including biomass, litter, and dead timber, the data were used of the State Forestry Register as of January 1, 2011 differentiated for the subjects of the Russian Federation. The methods and the special software worked out by the Center for the Forest Ecology and Productivity of Russian Academy of Sciences were used for the computations [2, 5]. The results of the assessment of the amount of organic matter available for combustion for forest lands are presented in Table 1. The average reserves of organic matter available for combustion in Russia amounted to 121.8 t/ha for forested lands and 21.3 t/ha for non-forested lands. The assumption was made for peat-bog fires that the average amount of fuel available for combustion (including the soil organic matter) is 120 t/ha [8].

The burn-up factors of organic matter were taken from [7]. The assessment of black carbon emissions from forest fires was carried out using the formula from [8]:

$$L_f = AM_bC_fG_{ef} \times 10^{-3} \quad (1)$$

where L_f is black carbon emission from the fire, t; A is the fire area, ha; M_b is the mass of the fuel available for combustion, t/ha, including biomass, litter, and dead fallen wood; C_f is the dimensionless burn-up factor (the following values are used: 0.43 ± 0.21 for crown fires, 0.15 ± 0.08 for ground fires, 0.5 ± 0.25 for underground fires, and 0.34 ± 0.17 for the non-forested areas of forested lands in boreal forests (according to Table 2.6 from [8])); G_{ef} is the black carbon emission factor, g/kg of combusted dry matter (G_{ef} = 0.56 ± 0.19 for crown

Table 1. The amount of organic matter available for combustion on the forest lands (t/ha)

Federal district	Parameter	Forested lands				Non-forested lands			
		Bio-mass	Dead timber	Litter	Total	Bio-mass	Dead timber	Litter	Total
Central	Mean	135.3	29.5	14.7	179.5	13.2	0.6	12.0	25.8
	Minimum	121.3	24.1	11.3	156.8	8.5	0.2	8.8	17.5
	Maximum	172.9	37.7	15.4	226.1	27.5	1.8	14.3	43.6
North-Western	Mean	87.2	20.7	28.6	136.5	7.8	0.3	19.3	27.4
	Minimum	32.9	8.1	14.2	55.3	5.6	0.1	11.9	17.6
	Maximum	156.5	32.2	31.2	220.5	18.1	0.7	22.7	41.5
Southern	Mean	144.7	23.5	11.7	179.9	11.4	0.4	8.9	20.7
	Minimum	51.9	8.0	11.0	70.9	8.9	0.2	8.2	17.3
	Maximum	185.3	28.7	12.9	226.9	19.8	1.2	11.0	32.0
North Caucasian	Mean	144.7	23.5	11.7	179.9	11.4	0.4	8.9	20.7
	Minimum	24.8	3.1	11.0	38.9	6.3	0.2	8.2	14.7
	Maximum	204.1	32.2	13.1	249.4	24.1	2.4	11.0	37.5
Volga	Mean	114.5	26.0	19.4	159.9	10.6	0.4	14.2	25.1
	Minimum	97.9	16.5	11.8	126.2	6.5	0.2	8.4	15.1
	Maximum	144.2	30.9	25.4	200.5	23.4	1.0	17.3	41.7
Ural	Mean	83.4	18.2	24.8	126.4	10.1	1.5	17.2	28.7
	Minimum	54.6	11.4	12.8	78.7	5.2	0.1	8.7	14.0
	Maximum	116.4	28.1	32.1	176.7	13.5	2.1	22.1	37.7
Siberian	Mean	97.8	18.5	12.2	128.5	9.2	2.1	11.0	22.3
	Minimum	75.6	15.1	8.6	99.3	5.8	0.2	7.5	13.4
	Maximum	138.0	24.4	12.8	175.2	14.5	3.2	11.6	29.4
Far Eastern	Mean	68.5	11.9	10.8	91.2	10.5	1.0	8.7	20.3
	Minimum	19.0	3.4	7.7	30.1	5.7	0.4	7.1	13.1
	Maximum	120.6	19.8	13.3	153.7	16.7	2.5	9.7	28.9
The Russian Federation	Mean	88.2	17.6	16.0	121.8	10.1	1.3	9.9	21.3
	Minimum	19.0	3.1	7.7	30.1	5.2	0.1	7.1	13.1
	Maximum	204.1	37.7	32.1	249.4	27.5	3.2	22.7	43.6

and ground fires and for the fires in non-forested areas, $G_{ef} = 0.20 \quad 0.11$ for underground fires, and $G_{ef} = 0.91 \quad 0.41$ for the non-forested areas of forest lands [10]).

The uncertainty was consecutively estimated for the emissions due to each type of fires in every region. After that the error of total emissions in the region and in the whole country was determined. The normal probability distribution was applied to all variables used for the computations. To estimate the uncertainty of the product, the following formula was used:

$$U_{tot} \quad U_1^2 \quad U_2^2 \quad \ldots \quad U_n^2 \tag{2}$$

and the following formula was used for the summing:

$$U_{tot} \quad [(U_1 x_1)^2 \quad (U_2 x_2)^2 \quad \ldots \quad (U_n x_n)^2] / (x_1 \quad x_2 \quad \ldots \quad x_n) \tag{3}$$

where U_{tot} is the total uncertainty of the product or sum, respectively, %; U_1, U_2, …, U_n are the uncertainties associated with each variable, %; x_1, x_2, …, x_n are the values of variables.

According to the published computations [1], the uncertainty of the biomass available for combustion is 32% for biomass, 38% for dead timber, and 63% for litter. The final values of the total uncertainty in percents were converted into absolute values.

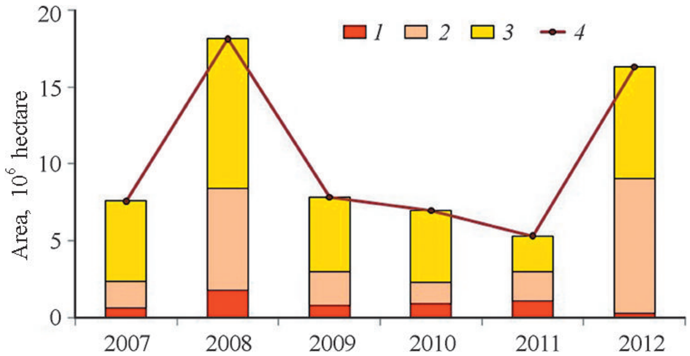

Fig. 1. The dynamics of the area of wildfires on the forest lands in 2007–2012. (*1*) Crown fires; (*2*) ground fires; (*3*) fires in the areas not covered with forests; (*4*) total area of fires.

RESULTS AND DISCUSSION

According to the data of the State Forestry Register as of January 1, 2011, the total area of lands where forests are located in the Russian Federation, amounted to 1183.3 10^6 ha including the area of the forest fund lands equal to 1144.1 10^6 ha. The forest lands do not include the areas of the forests controlled by the Ministry of Defense of the Russian Federation and urban forests (6.2 10^6 ha), the lands of specially protected natural reservations (SPNR; 26.2 10^6 ha), and the lands of forests of other categories (6.8 10^6 ha). The area of lands where forests are located, includes the forested lands covered and not covered with forest vegetation (felling areas, burnt forests, dead stands, open forest crops, under-stocked stands, etc.) and the areas of non-forested lands within the limits of forest areas (hayfields, pastures, wetlands, farmsteads, cuttings, roads, etc.). The data on fires collected by the Rosleskhoz are referred both to the forested and non-forested areas of forest lands.

The total area of fires varied from 5.3 10^6 ha in 2011 to 18.1 10^6 ha in 2008 (Fig. 1). In the forested areas in 2008 and 2010 fires made up 46.5 and 33.0%, respectively, of the total area of fires. Fires on non-forested lands prevailed and occupied 54–69% of the total area covered by fires. In 2011 and 2012, fires on forested lands started prevailing (55–56% of the total fire area). As to fires on forested lands, ground fires prevail and the contribution of crown fires made up from 3 to 40%. As compared with the other types of fires, the areas of underground fires are relatively small (from 0.18 10^3 ha in 2009 to 14.44 10^3 ha in 2010) and not presented in Fig. 1.

In 2007–2012 the average emission of black carbon as a result of wildfires amounted to (81.9 37.2) 10^3 t/year (Table 2). The obtained estimates turned out to be a bit lower than the average annual estimates of black carbon emission made by A.Z. Shvidenko and D.G. Shchepashchenko [9] which amounted to about (120 28) 10^3 t/year for the period of 1998–2010. The difference in the estimates can be associated with different approaches to the estimation of the burnt matter mass and with the fact that paper [9] analyzes the larger area of fires, that is, takes into account all wildfires on the territory of Russia. The present paper gives estimates only for fires on forest lands. Besides, the black carbon emission factor used by the authors of [9] makes up 0.1% of the content of total carbon in the burnt material that by 2–5 times exceeds the special fire-type factors used in the present paper.

Paper [12] presents the similar estimate of the current emission: 120 10^3 t of black carbon per year. However, it was obtained for the emissions from all types of open biomass combustion but not only from forest fires; for the territory of the former USSR (not of the Russian Federation only).

Crown fires are the most dangerous judging by black carbon emissions and by the degree of their impact on the climate system. The burnt-up factor of biomass available for combustion for this type of fire is maximum that is manifested in the significant specific volume of black carbon emissions. When converted to 1 ha of fire area, it is equal to 25.0 3.7 kg/ha. The height of black carbon emission in the case of the crown fire is also maximum that causes the longer lifetime of particles in the atmosphere, the larger distance of their transport, and, hence, the high probability of black carbon deposition on the snow in the Arctic.

The average value of emissions from crown fires for the period under consideration amounted to 22.7 10^3 t of black carbon or 27.7% of total emission (Table 2). The high variability of emissions from this type of fires is observed. For example, 43.4 10^3 t of black carbon was emitted as a result of crown fires in 2008

Table 2. Black carbon emissions for different federal districts and types of forest fires in 2007–2012

Federal district	Black carbon emission, t											
	2007		2008		2009		2010		2011		2012	
Crown fires												
Central	571	209	18	10	30	11	7656	3007	240	69	0	
North-Western	98	36	6	4	9	5	45	22	1529	762	0	
Southern	94	63	2	2	14	7	133	72	62	32	0	
North Caucasian	53	24	0		77	55	13	5	0		0	
Volga	80	36	28	8	30	10	7129	2399	124	48	0	
Ural	792	390	580	334	188	63	1260	507	1755	733	2414	1470
Siberian	12706	5743	14892	6275	3911	1619	4371	1600	9766	3676	2969	1179
Far Eastern	3085	1092	27891	12560	10865	4624	5301	2277	13208	6772	1800	766
The Russian Federation	17479	5863	43418	14044	15124	4900	25908	4775	26683	7778	7183	2034
Ground fires												
Central	1017	373	429	135	1627	438	3617	1369	178	56	140	61
North-Western	140	41	206	75	171	67	441	191	1018	528	115	53
Southern	2797	1951	101	51	98	50	21	12	19	8	7	3
North Caucasian	662	398	12	5	354	127	12	4	5	2	5	2
Volga	178	73	277	74	981	310	4383	1490	69	20	58	20
Ural	325	145	4736	2626	624	264	3807	1750	2086	909	14844	8433
Siberian	7927	2743	37439	14577	4576	1478	2897	1156	7055	2779	30389	11775
Far Eastern	6206	2464	20933	10143	13931	5541	1428	539	7075	3343	31400	14470
The Russian Federation	19251	4210	64132	17953	22362	5768	16607	2970	17504	4473	76957	20473
Underground fires												
Central	21	12	1	0.5	1	0.2	221	117	4	2	0	
North-Western	1	0.5	1	0.3	0		1	0.8	1	0.6	0	
Southern	0		0		0		0		0		0	
North Caucasian	0		0		0		0		0		0	
Volga	1	0.6	1	0.5	1	0.30	112	48	1	0.4	0	
Ural	0		2	1	2	1	11	4	2	1	3	1
Siberian	27	19	0		0		1	1	2	1	4	1
Far Eastern	96	51	20	13	1	0.4	0		13	9	13	7
The Russian Federation	146	56	26	13	4	1	347	127	22	9	20	8
Fires in the areas not covered with forests and on non-forested lands												
Central	3109	947	936	276	7472	1721	5309	1307	994	225	158	71
North-Western	24	2	246	87	541	281	128	40	541	331	30	12
Southern	6106	3452	443	195	977	435	172	90	315	149	23	12
North Caucasian	853	351	168	97	619	293	147	52	29	13	24	13
Volga	382	126	1628	483	3314	970	7839	1949	667	185	111	38
Ural	511	258	4273	2120	699	274	2589	976	1452	602	9898	4621
Siberian	7768	3594	19956	6823	2625	811	2429	687	2935	897	11441	3798
Far Eastern	2846	1282	8031	3760	4609	1573	1815	659	2455	1203	6459	2780
The Russian Federation	21599	5251	35681	8097	20855	2732	20428	2716	9389	1682	28144	6596

that exceeds the emissions in 2012 by 6 times (7.2 10^3 t). The maximum contribution was made by crown fires in 2010: 41% of the total emission of black carbon from all types of fires per year.

The impact of ground fires on the climate system is less significant than that of crown fires due to the smaller height of black carbon emission and much less significant specific volume of black carbon emissions per 1 ha amounting to 10.2 1.2 kg/ha. However, they represent not smaller danger in view of the total volume of emissions. For example, the average long-term emission of black carbon from ground fires is 36.2 10^3 t (Table 2) or 44.2% of average long-term emission. The volume of emissions of this type varies from 16.6 10^3 t in 2010 (26.2% of annual emission) to 77.0 10^3 t in 2012 (68.5% of annual emission).

The average specific emission of black carbon from underground fires is comparable with that of crown fires: 24.0 0.1 kg/ha. The value of this type of fires is minimum taking into account that the area of underground fires and the emission height are minimum. The average emission of black carbon from this type of fires for the period under consideration is 94.3 t/year (Table 2) or 0.1% of total average annual volume of emissions. The variability of emissions from underground fires is maximum among all types (by more than 86 times): from 4 t of black carbon in 2009 to 347 t in 2010.

The average specific emission of black carbon from fires in the areas not covered with forests and on non-forested lands is minimum among all types of fires and is equal to 4.1 0.3 kg/ha. However, due to the large areas of the fires of this type, their contribution is significant and makes up 28.0% of total average annual emission. The average emission of black carbon from fires in the areas not covered with forests and on non-forested lands is 23 10^3 t. The minimum values of emissions from the fires of this type are equal to 9.4 10^3 t (17.6% of annual emission) in 2011 and the maximum values, 35.7 10^3 t (37.1% of total annual emission) in 2008.

The average uncertainty in the estimates of black carbon emissions varies from 69 to 74% for different types of fires (the absolute values of uncertainty are given in Table 2). The total uncertainty in federal districts decreases to 20–45% and varies from year to year from 8 to 17% for the country as a whole.

On average, in 2007–2012 the maximum contribution to black carbon emission on the territory of the Russian Federation was made by fires in the areas covered with forests (Table 2). At the same time, regional differences are observed in the contribution of fires of different types. For example, the main contribution to black carbon emission was made by the areas not covered with forests and on non-forested lands in the Central, Southern, North Caucasian, and Volga federal districts and by ground and crown fires on the forested lands in the North-Western, Ural, Siberian, and Far Eastern federal districts.

Black carbon emissions are characterized by significant interannual variability associated not only with the variations of the total area of fires but also with the different values of the area of different types of fires in different years. In some years the maximum volume of black carbon emissions due to fires exceeds the minimum values by more than 400 times (for example, if compare emissions in 2010 and 2008 in the Central Federal District) (Table 2).

The consideration of average annual emissions of black carbon from different types of fires in 2007–2012 enables assessing the dynamics of fires in general and identifying the regions with significant yearly emission (Fig. 2). The minimum values of black carbon emission due to fires were registered in the North-Western, Southern, and North Caucasian federal districts; the medium values, in the Central, Volga, and Ural federal districts; and the maximum values, in the Siberian and Far Eastern federal districts.

In the European part of Russia, the maximum values of black carbon emissions were registered in the Ryazan and Nizhny Novgorod oblasts and the Krasnodar krai. In the first two regions the huge contribution was made by crown and ground fires in 2010 and in the Krasnodar krai, by ground fires and fires in the areas not covered with forests and on non-forested lands in 2007.

The maximum values of black carbon emissions in the Urals and West Siberia were observed in the Khanty-Mansiysk autonomous okrug and the Tyumen and Sverdlovsk oblasts. The maximum contribution was made there by ground fires and fires in the areas not covered with forests and on non-forested lands in 2012.

The territories of Central and East Siberia and the Far East of Russia are the main emitters of black carbon in the Russian Federation. The maximum average annual emissions of black carbon for the period under consideration were registered in the Amur oblast, Zabaikal'skii krai, and Sakha (Yakutia) Republic. In the Zabaikal'skii krai, the maximum contribution was made by crown fires and by the fires in the areas not covered with forests and on non-forested lands in 2007 and 2008; also, by ground fires in 2008 and 2012. In the Amur oblast, the greatest contribution was made by crown fires in 2008 and by ground fires in 2008 and 2012. In Sakha (Yakutia) Republic, the maximum contribution was made by crown fires in 2008, 2009, and 2011 and by ground fires in 2008 and 2012.

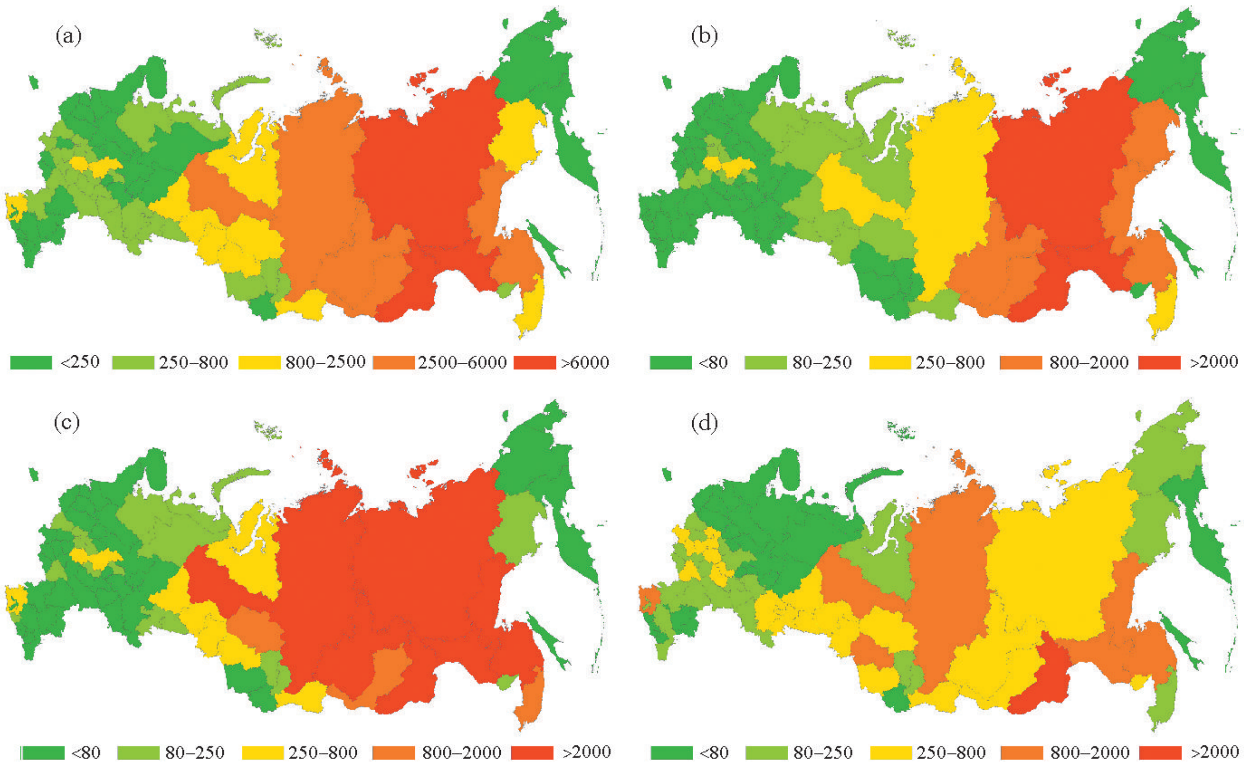

Fig. 2. Average annual emission of black carbon (t) from different types of fires on the forest lands of Russia in 2007–2012. (a) Total average annual emission of black carbon; (b) from crown fires; (c) from ground fires; (d) from fires in the areas not covered with forests and on non-forested lands.

The reason for the regional differences is, on the one hand, the practice of forest fire protection and, on the other hand, the weather conditions. For example, the ground-based type of forest fire protection organization prevails in the European part of Russia and in the Urals; it prevents fires rather efficiently. However, under the conditions of extreme natural phenomena, it may be insufficient (for example, the extreme heat in 2010) that results in significant fires and, hence, in the larger emissions of black carbon. The zone of airborne and spaceborne monitoring of fires is large in Siberia and the Far East. The fire fighting takes place only if fires threaten infrastructural objects or settlements. Therefore, in these regions fires occupy larger areas and result in the more significant emissions of black carbon. However, their interannual variability is rather low because each fire burns the maximum available volume of organic matter.

Thus, to carry out the computational monitoring, it is important to consider not only the general spatial distribution of black carbon emissions on the territory of Russia but also to carry out the differentiation between fire types. Taking into account that in winter and spring precipitation is more essential from the point of view of the variations of snow albedo in the Arctic, the inclusion of seasonal fluctuations of emissions due to wildfires should be the next step of the development of the system of computational monitoring.

CONCLUSIONS

The basic emissions of black carbon as a result of fires in 2007–2012 were registered in Siberia and the Far East that was associated with the significant areas of fires and with the high contribution of crown fires. The reasons for such phenomenon are, on the one hand, forestry practice and, on the other hand, natural conditions. For example, the fire fighting is carried out only if fires threaten infrastructural objects or settlements. Therefore, in these regions fires occupy larger areas and, hence, cause the more significant emissions of black carbon.

The maximum average volume of black carbon emissions converted to the fire area of 1 ha was registered for crown fires and amounted to 25.0   3.7 kg/ha. The average emission of black carbon is 24.0   0.1 kg/ha for underground fires, 10.2 1.2 kg/ha for ground fires, and 4.1 0.3 kg/ha for fires in the areas not covered with forests and on non-forested lands. The average value of the total emission of black carbon from fires on forest lands amounted to 81.9 37.2 t/year in 2007–2012.

According to the data available in literature [12], black carbon has the Global Warming Potential (GWP) of 900 (100–1700) for the period of 100 years that makes it one of the strongest factors of the climate warming. Judging by its impact on the climate, black carbon is the second (in significance) substance after carbon dioxide among all anthropogenic greenhouse agents. Considering the volume of black carbon emissions and the absence of their routine monitoring makes clear that there is a large gap in the Russian system of the accounting of greenhouse gas emission. Thus, one of the pressing objectives of the development of the system of computational monitoring of greenhouse agents is the account of black carbon emissions on the permanent basis with the spatial and seasonal detailing.

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