Large-scale hazes over Eurasia in July 2016: Siberian smoke haze evolution

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Large-scale hazes over Eurasia in July 2016: Siberian smoke haze evolution

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Abstract. Using the aerosol optical depth (AOD) data from the MODIS satellite instruments, the hazes over Eurasia in July 2016 were analyzed. Total area of the haze blanketing was estimated to be approximately 20 million km^2, including the Siberian smoke haze (SSH) with a maximum area of 16 million km^2, spreaded over European territory of Russia, Kazakhstan and many European countries. The evolution of AOD in SSH has been analyzed. The total mass of smoke at different stages of the SSH evolution was ranged from 1.6 to 3.7 million tons. When using the aerosol index data from the OMI UV measurements, the essential changes in the qualitative composition of smoke aerosol transported away from the fire places at a distance of 1000-2000 km were detected. The average aerosol radiative forcing at the top of the atmosphere and at the stage of maximum development of the SSH was estimated to be -38 W/m^2.

1. Introduction

Atmospheric aerosol impacts directly and indirectly on the radiative regime of the atmosphere. There are significant uncertainties of the radiative regime, which introducing by sporadic large-scale hazes.

The large-scale hazes with a total area of about 20 mln km^2 observed over Eurasia in July 2016 [1] including smog over Northern China Plain (2 mln km^2), a dust haze in the neighborhood of Taklimakan desert (0.8 mln km^2) and dense haze on the Pakistan and India territory (of about 1 mln km^2). In July 2016 Siberian smoke haze (SSH) was extreme by an area size (16.3 mln km^2) [1] owing to anomalous eastern transport [2, 3].

In this article four stages of the SSH evolution in the time periods 15-18 July (I), 19-22 July (II), 23-26 July (III) and 27-31 July 2016 (IV) are analyzed.

2. Aerosol optical depth variations

The SSH extent scale over Eurasia in July 2016 can be evaluated using aerosol optical depth (AOD) monitoring data for wavelength 550 nm obtained by a spectroradiometer MODIS (Terra platform) [4]. AOD spatial distributions with resolution 1^{o}N x 1^{o}E for the abovementioned stages of SSH evolution are shown on Fig. 1 for the area restricted by the coordinates 40^o-70^{o}N and 0^o-140^{o}E.

It should be noted that there were two small additional sources of aerosol in the Northern Eurasia besides SSH: dust haze in neighborhood Aral sea and the smog over Northern China Plain.

Average AOD or τ at the gathering stage SSH was equal 0.25 (Table 1) and the peak AOD value τ_{max}=4.62 (for pixel centered at 61.5^o N and 99.5^o E). Statistical characteristics of AOD variations were calculated including variation coefficient γ and asymmetry parameter A (Table 1). AOD empirical function distribution is shown on Fig. 2a (curve 1).

SSH on stage I was located predominantly in Siberia (Fig. 1a) and AOD (which characterizes smoke haze intensity) did not exceed as a rule 2.0. Probability distribution (1 on Fig. 2a) describes comprehensively AOD variations on stage I. For AOD interval from 0.6 to 2.0 this probability distribution can be approximated by exponential function $w = 31 \exp(-\tau/0.34)$.

Smoke mass M in the atmospheric column can be evaluated using the relation $M = 0.25\ \tau$ (g/m^2), obtained in [5,6]. The total smoke mass on the stage I was equal 1.61 mln tons or 1.61×10^{12}g. (Table 1).

On stages II and III average values of AOD reached 0.47 and 0.57 (Table 1) respectively and τ_{max} at stage III – 4.65, relatively small value $\tau_{max} = 4.15$ at stage II is due supposedly to cloud screening. In these periods a forest fire areas increased significantly that is confirmed by AOD probability distribution (2 and 3 on Fig. 2a), which are approximated by exponential function $w = 22.9 \exp(-\tau/0.565)$ for interval $0.4 < \tau < 2.0$ (Stage II) and $w = 20.1 \exp(-\tau/0.67)$ for $0.4 < \tau < 2.4$ (Stage III).

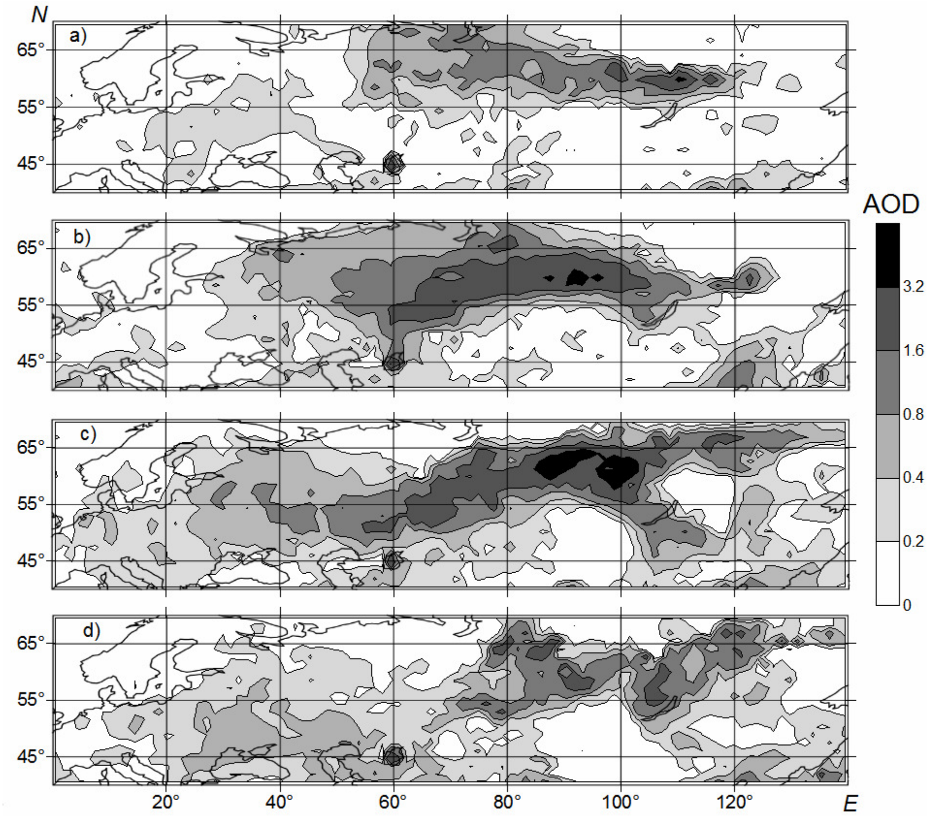

Figure 1. AOD spatial distribution: 07.15-07.18 (a), 07.19-07.22 (b), 07.23-07.26 (c), 07.27-07.31 (d).

Total mass of smoke achieved: 3.03 and 3.65 mln tons for stage II and III, respectively.

During stages II and III the long-range transport of SSH fragments took places. At stage II SSH began to spreads to European part of Russia (EPR). At stage III SSH spread practically onto the whole EPR and ranged up to many Europe countries from Finland to Bulgaria and from Belorussia to Germany and also Kazakhstan.

At the weakening stage (IV) the forest fire area was diminished markedly and the smoke haze area at EPR was decreased. But SSH transport in Europe was continued until July 31. Average AOD was equal 0.36 and the total smoke mass – 2.32 mln tons. AOD probability distribution is shown on Fig. 2a (curve 4). It is approximated by the function $w = 20.1 \exp(-\tau/0.58)$ for interval $0.6 < \tau < 2$.

Table 1. Siberian smoke haze parameter variations for four time periods in July 2016.

The time period	<τ>	γ	A	τ_{max}	N	E	M, 10^{12} g
07.15-07.18	0.25	1.40	4.62	4.70	61.5°	99.5°	1.61
07.19-07.22	0.47	1.35	2.49	4.15	59.5°	96.5°	3.03
07.23-07.26	0.57	2.26	2.73	4.85	61.5°	88.5°	3.65
07.27-07.31	0.36	1.11	3.35	4.63	64.5°	87.5°	2.32

Table 2. Siberian smoke haze parameter variations for four time periods in July 2016.

The time period	<AI>	AI_{max}	N	E	$<R>$, W/m^2	γ	A
07.15-07.18	0.91	3.35	60.5°	106.5°	−18.3	1.17	2.91
07.19-07.22	1.08	4.44	60.5°	99.5°	−31.4	1.14	1.91
07.23-07.26	1.17	5.88	59.5°	98.5°	−37.6	1.00	1.77
07.27-07.31	0.89	3.61	55.5°	107.5°	−25.8	0.94	2.40

3. Variations of aerosol index during Siberian smoke haze

Many scientists are interested in study composition of the smoky atmosphere including smoke aerosol (SA) composition transformation (aerosol aging). According to AERONET data [7] the smoke aerosol, which transported in Central Europe from Siberia was characterized by similarity with that at EPR during the forest fires in 2010 [8]: the fine mode dominated in the particle size distribution and absorption of SA was weak (single scattering albedo exceeded frequently 0.95-0.96).

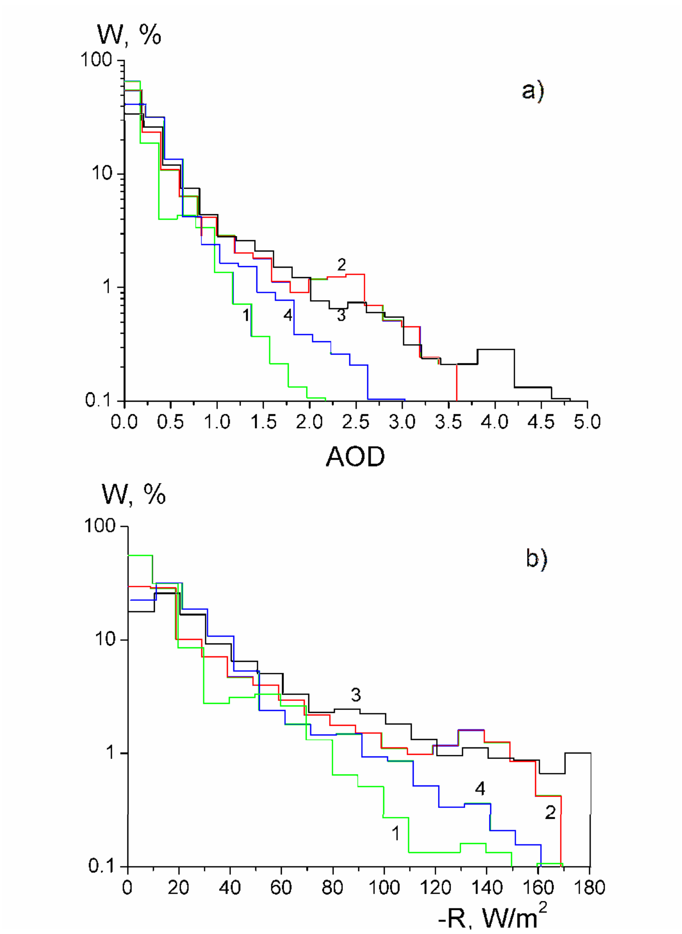

Figure 2. Probability distribution of AOD (a) and aerosol radiative forcing at the top of the atmosphere (b): 07.15-07.18 (1), 07.19-07.22 (2), 07.23-07.26 (3), 07.27-07.31 (4).

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SA qualitative composition variations can be found from the measurement data of the aerosol index [9,10] AI = 100 [$\lg\eta_{mes} - \lg\eta_{cal}$], where $\eta = J_{360}/J_{331}$, J_{360} and J_{331} - outgoing radiation intensities for wavelengths 360 and 331 nm, "mes" and "cal" indicate the procedure of the intensity assessment (measurement or calculation). Spatial distributions of AI are presented at Fig. 3. In the process of SSH evolution average (maximal) values AI grow from 0.9 (3.35) to 1.08 (45.44) and next to 1.17 (5.88), reducing at stage IV to 0.89 (3.61). Notice that the coordinates AI_{max} do not coincide at the different stages and do not coincide with τ_{max} coordinates. Increased AI areas approximately coincide with the intensive burning areas, where extreme AOD values are observed. In other words extreme AI are inherent to "fresh" smoke. AI diminishes markedly within 1000-2000 Km from the forest fire location.

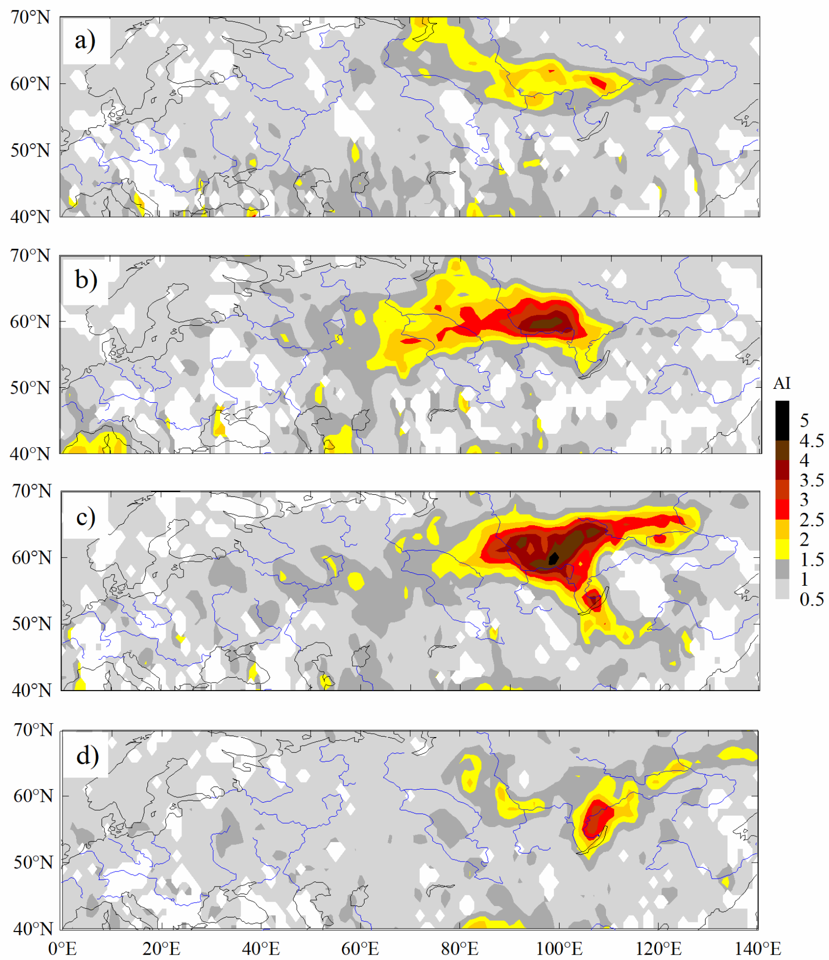

Figure 3. Spatial distributions of aerosol index: 07.15-07.18 (a), 07.19-07.22 (b), 07.23-07.26 (c), 07.27-07.31 (d).

4. Siberian smoke haze radiative impact

Large-scale haze radiative impact assessments were received previously for EPR and Siberia [6]. In this work aerosol radiative forcing (ARF) assessments at the top of the atmosphere are given for the area restricted by the coordinates 40°-70° N and 0°-140° E for stages I-IV of SSH evolution (Fig. 4), when average values ARF were equal -18.3, -31.4, -37.6 and -25.8 W/m^2 (Table 2). It was shown [11] that ARF at EPR on 24 and 25 July 2016 reached -29 W/m^2. Value $|R|$ at stages II and III exceeded 100 W/m^2 at a substantial part of Siberia. Detection probability of R in SSH can be evaluated by the probability distribution function (Fig. 2b) which are approximated by exponential function w = C exp (R/R_o), where R_o for stages II, III and IV equals 33, 54 and 30 W/m^2 and parameter C = 21.4, 14.4 and 27.4, respectively. These approximations are valid for $20 < |R| < 160$ W/m^2 (IV). Statistical characteristics of R are given in Table 2.

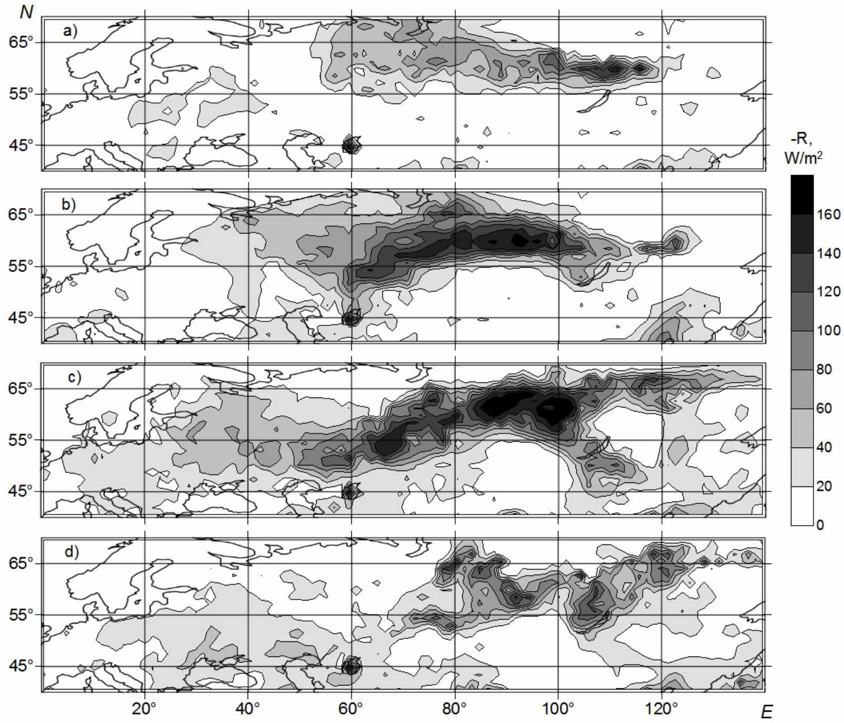

Figure 4. Spatial distributions of the aerosol radiative forcing at the top of the atmosphere: 07.15-07.18 (a), 07.19-07.22 (b), 07.23-07.26 (c), 07.27-07.31 (d).

5. Conclusion

AOD, AI and ARF spatial distributions have been analyzed. For variations of the above-mentioned parameters the statistical characteristics including average value, variation coefficient, asymmetry and excess were calculated. The total smoke aerosol mass was estimated for four stages of SSH to be 1.61, 3.03, 3.65 and 2.32 mln tons.

6. Acknowledgments

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