Estimation of aerosol radiative forcing based on measurements at Zvenigorod scientific station of IAP RAS in March 2004

I.A. Gorchakova, P.P. Anikin, and E.V. Romashova

A.M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow

Received February 7, 2006

Variability of optical thickness, single scattering albedo, asymmetry factor of the aerosol scattering phase function, is examined in the paper based on measurement data obtained in the cloudless atmosphere in March 2004 at the Zvenigorod Scientific Station of A.M. Obukhov Institute of Atmospheric Physics RAS. The monthly mean values of the short-wave aerosol radiative forcing at the boundaries of the atmosphere under clear sky conditions have been obtained. The aerosol optical parameters and the estimates of aerosol radiative forcing (mean for March) derived from the measurements data of 2004 and with the use of data obtained during the Zvenigorod Aerosol–Cloud–Radiation Experiments in 2001 and 2002 are compared.

Systematic ground-based measurements of optical and radiation parameters of the atmosphere have been carried out at Zvenigorod Scientific Station (ZSS) of A.M. Obukhov Institute of Atmospheric Physics of the Russian Academy of Sciences (IAP RAS) since 2001. In this paper we consider variability of the optical thickness, single scattering albedo, and the asymmetry factor of the aerosol scattering phase function in the visible range obtained in March 2004 under clear sky conditions. The values of the above-mentioned aerosol characteristics in the shortwave range of the spectrum calculated for March based on the measurement data obtained in 2004 and on data obtained during the Zvenigorod Aerosol–Cloud–Radiation Experiments (ZACREX) in 2001 and 2002 are compared.

The optical and microphysical parameters of aerosol were determined from the data of radiative and photometric measurements. Direct and diffuse fluxes of solar radiation at 5 wavelengths (414.5; 497.3; 613.5; 671.6; and 868.8 nm) were measured with MFRSR (Multi-Filter Rotating Shadowband Radiometer). The data of MFRSR were used for estimation of the aerosol optical thickness and single scattering albedo. The aerosol optical thickness at the effective wavelength of 550 nm τ_{550} and the Ängström exponent α were determined for each moment from the spectral aerosol optical thickness in the visible range. The instrumentation and techniques used for reconstruction of the aerosol optical and microphysical parameters from the data of radiative measurements have been described in detail in Ref. 1.

The reconstructed aerosol parameters were used for determination of the shortwave aerosol radiative forcing (ARF). We have estimated both instantaneous (measurements were carried out every 2 minutes) and mean ARF at the boundaries of the atmosphere in the periods of clear sky during daylight time for a month. The values of ARF were determined as the difference between the effective total fluxes calculated taking into account aerosol and ignoring it. The total radiative fluxes in the shortwave portion of the spectrum were calculated by the δ-Eddington method for solving the radiation transfer equation using the integral transmission function of the atmosphere.[2] This technique takes into account molecular scattering, absorption by molecular atmospheric gases (H_2O, CO_2, O_3, O_2), and extinction of solar radiation by aerosol and cloud particles.

Estimates of ARF were obtained for the cloudless atmosphere. In the absence of visual estimate, the presence of clouds was determined as follows. First, the ratio between the aerosol optical thickness at the wavelengths of 868.8 and 497.3 nm (Fig. 1) was estimated. If the value of this ratio had been greater than 0.7, the presence of semitransparent clouds on the sun disk was supposed. It is clear that false relation to cloudy situation is possible if using this criterion in situations with small Ängström exponent. Another one criterion of the presence of clouds can be synchronous variations of the optical thickness at five wavelengths by the same factor (Fig. 1). The basis of this approach (disputable, in principle) is the fact that, as a rule, the size of cloud particles is larger than the size of aerosol particles and larger than the wavelengths in the considered range (497.3–868.8 nm). Mean extinction of solar radiation by clouds in the visible and near IR ranges is close to neutral, different from selective behavior of the aerosol extinction of solar radiation.

It is seen from Fig. 1, how stable was the state of the atmosphere on March 14, 2004. On this date the clear sky conditions were observed practically during all daylight hours.

0235-6880/06/06 431-03 $02.00

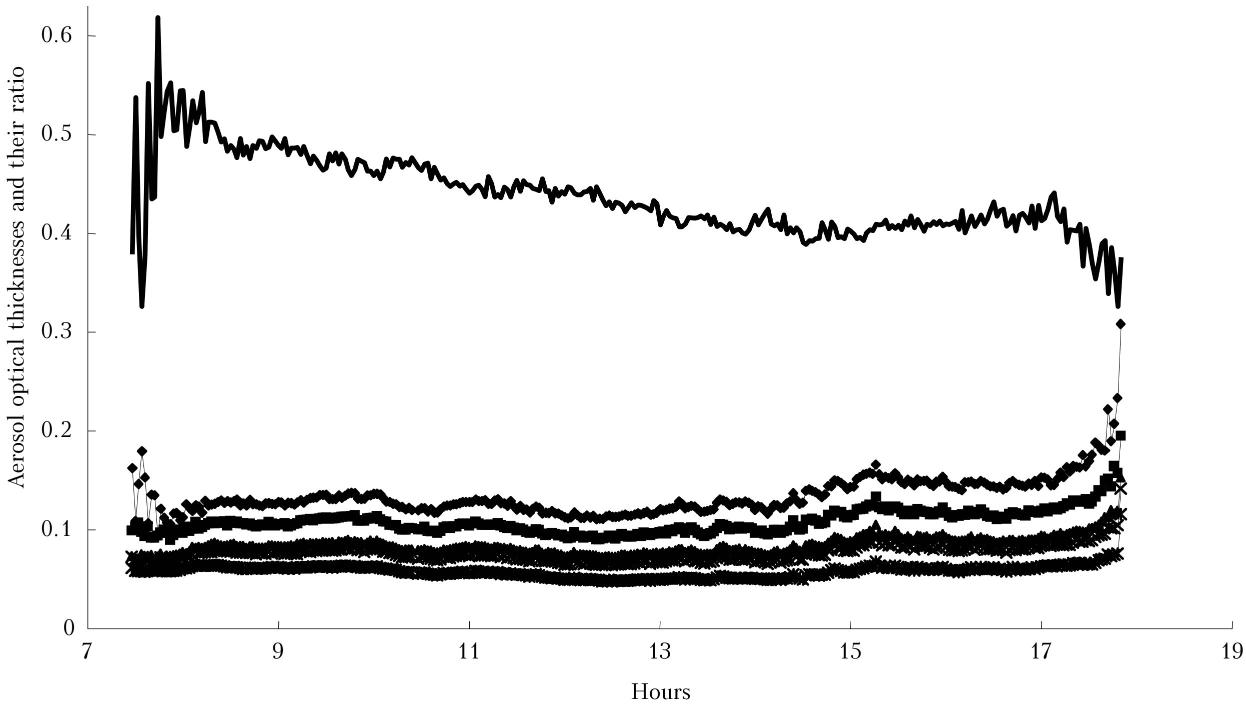

Fig. 1. Aerosol optical thickness in the visible range on March 14, 2004. The ratio of the aerosol optical thickness at the wavelengths of 868.8 and 497.3 nm: (—◆—) 414.5; (—■—) 497.3; (—▲—) 613.5; (—×—) 671.6; (—✱—) 868.8; (━━) 868.8/497.3.

Table 1. Aerosol optical thickness τ_{550}, single scattering albedo ω_{550}, and asymmetry factor g_{550} at the wavelength of 550 nm, Ängström exponent α, averaged over each period of observations; n is number of measurements during the period; w is column density of water vapor of the atmosphere

Days	Hours	τ_{550}	ω_{550}	g_{550}	α	A_s	n	w, cm	ARF(0)	ARF(∞)	ARF(∞)–ARF(0)
03.05.2004	14:08–15:40	0.138	0.870	0.60	–1.40	0.23	39	1.90	–21.9	–5.5	16.4
03.11.2004	12:58–17:52	0.069	0.805	0.63	–1.03	0.21	133	0.85	–12.4	–3.1	9.3
03.14.2004	9:30–17:00	0.089	0.79	0.63	–1.08	0.20	255	1.06	–34.6	–6.6	28
03.29.2004	15:40–18:00	0.087	0.64	0.62	–1.00	0.11	71	0.07	–40.4	–10.6	29.8
03.30.2004	12:46–17:48	0.085	0.51	0.63	–1.02	0.11	116	0.06	–42.2	–7.7	34.4

Time intervals strictly selected on the days in March 2004, when clear sky conditions were observed, are presented in Table 1. The data on the aerosol optical parameters at the wavelength of 550 nm are also presented there.

The values of the surface albedo A_s (from the MODIS data), column density of water vapor of the atmosphere w (cm), and the value of the aerosol radiative forcing at the surface ARF(0), at the top of the atmosphere ARF(∞), and the atmospheric absorption ARF(∞)–ARF(0) are presented in Table 1.

According to our estimates (Table 1), the value τ_{550} in March 2004 varied within the limits from 0.06 to 0.16. As a rule, the value of the aerosol optical thickness at the wavelength of 550 nm during March 2004 oscillated about 0.1. The value τ_{550} on March 5 varied within the range from 0.13 to 0.16 during cloudless period of observations. These values of the optical thickness τ_{550} are characteristic of the background aerosol regime observed at the ZSS.

The Ängström exponent α, according to our estimates, was a little but greater than 1 during March 2004, except for March 5. The Ängström exponent on March 5 did not exceed 1.40. The minimum value α in March 2001–2002 was equal to 1.36, and the maximum was 1.60. The values of the single scattering albedo (except for March 5, 0.51–0.81) were noticeably less than the value ω_{550} obtained from the data of ZACREX-2001 and ZACREX-2002 (0.86–0.91). The aerosol single scattering albedo ω_{550} on March 5 was equal to 0.87.

Low values of the aerosol single scattering albedo characteristic of cloudless periods of March 2004 can be partially explained by large errors appearing in using the D–D[1] method at small values of the aerosol optical thickness in the visible range.

The values of the asymmetry factor of the aerosol scattering phase function g_{550} were noticeably greater in March 2004 than in March 2001 and 2002. The minimum value of the asymmetry factor in March 2004, according to our estimates, was equal to 0.6, while in March 2001 and 2002 it was 0.52. The value of the total surface albedo A_s was calculated taking into account the corresponding solar component. The spectral surface albedo were determined from the data of satellite radiative measurements using MODIS (MODerate resolution Imaging Spectroradiometer) that were kindly presented at our disposal by our colleague, A.P. Trishchenko, from Canadian Center for Remote Sensing.

Temporal behavior of the spectral surface albedo during first half of 2004 in the region of Zvenigorod is shown in Fig. 2.

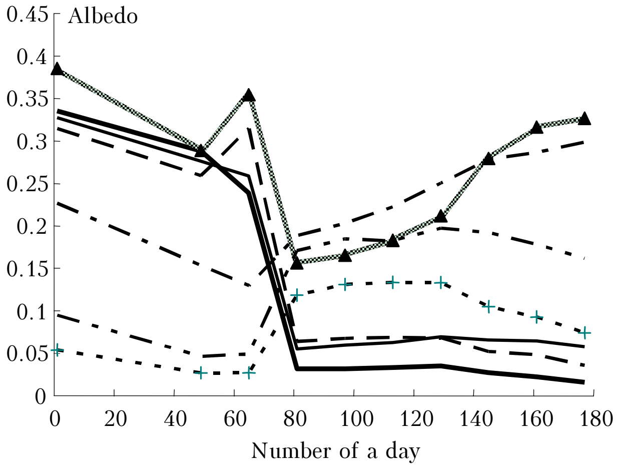

Fig. 2. Spectral albedo of the surface in the shortwave range: (▬▬) 469; (——) 555; (— —) 645; (▲) 858; (– · –) 1240; (— · ·) 1260; (- + -) 2130.

The total surface albedo A_s in March 2004, according to our estimates, varied from 0.23 (there was snow in the beginning of the month) down to 0.11. In calculating the total solar radiation fluxes, the value A_s equal to 0.40 was used for the data of March 2001, and A_s equal to 0.20 and 0.15 were used for March 2002 (the estimates of ARF presented below were obtained at $A_s = 0.20$).[3] According to our estimates (Table 2), mean values of ARF on clear sky days and periods of March 2004 at the surface are equal to -30 W/m^2, and at the top of the atmosphere (TA) -6 W/m^2, the atmospheric absorption is 24 W/m^2.

Mean values of the aerosol radiative forcing in March 2001 and 2002 are equal to, respectively, -12 and -32 W/m^2, and 1 and -10 W/m^2 at the top of the atmosphere. The obtained quantitative estimates of ARF at the top of the atmosphere in March 2004 well agree with the corresponding estimates[4] for the regions with the climate analogous to the climate of central part of Russia. Our estimates of ARF at the surface are slightly in excess of the corresponding estimates in Ref. 4. It should be noted that the estimates in Ref. 4 were obtained using larger data array (March–May). Moreover, the values of the total albedo used in calculations with the data of 2004 are small.

Table 2. Aerosol optical parameters, column density of water vapor of the atmosphere *w*, cm, surface albedo A_s, Ängström exponent α, mean values of ARF(*z*), W/m^2 (*z* is height) during March 2001, 2002, and 2004 under clear sky conditions

Parameter	Year		
	2001	2002	2004
τ_{550}	0.12–0.19	0.03–0.32	0.06–0.16
ω_{550}	0.86–0.87	0.87–0.91	0.51–0.87
g_{550}	0.53–0.59	0.52–0.59	0.60–0.63
α	−1.40–−2.10	−1.95–−2.30	−1.00–−1.40
A_s	0.40	0.20	0.11–0.23
w, cm	0.28–0.35	0.48–0.65	0.63–1.90
ARF(0)	−12	−32	−30
ARF(∞)	1	−10	−6
ARF(∞)–ARF(0)	13	22	24

Acknowledgments

Authors would like to thank M.A. Sviridenkov for the aerosol optical parameters and A.P. Trishchenko for the data on the spectral surface albedo kindly presented at our disposal.

The work was supported in part by Russian Foundation for Basic Research (grants No. 04–05–64579 and No. 05–05–65038).

References

1. T.A. Tarasova, I.A. Gorchakova, M.A. Sviridenkov, P.P. Anikin, and E.V. Romashova. Izv. Ros. Akad. Nauk, Fiz. Atmos. Okeana **40**, No. 4, 514–524 (2004).
2. I.A. Gorchakova, Izv. Ros. Akad. Nauk, Fiz. Atmos. Okeana **36**, No. 3, 376–386 (2000).
3. I.A. Gorchakova, I.I. Mokhov, and A.N. Rublev. Izv. Ros. Akad. Nauk, Fiz. Atmos. Okeana **41**, No. 4, 496–510 (2005).
4. H. Yu, Y.J. Kaufman, M. Chin, G. Feingold, L.A. Remer, T.L. Anderson, Y. Balkanski, N. Bellouin, O. Boucher, S. Christopher, P. DeCola, R. Kahn, D. Koch, N. Loeb, M.S. Reddy, M. Schulz, T. Takemura, and M. Zhou, Atmos. Chem. Phys. Discussions, No. 5, 7647–7768 (2005).