Aerosol Radiative Forcing Under Cloudless Conditions in Winter ZCAREX-2001

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Introduction

Aerosol radiative forcing (ARF) is estimated for winter clear-sky conditions from measurements during ZCAREX-2001–Cloud-Aerosol-Radiation Experiment in February-March, 2001 at the Zvenigorod Scientific Station (ZSS) of the A.M. Obukhov Institute of Atmospheric Physics RAS. ARF in the shortwave range is determined by the difference between the net fluxes of the solar radiation, calculated with and without the aerosol component of the atmosphere. The estimates of ARF are made for conditions with high surface albedo.

Data Used

The following data of atmospheric characteristics observed during winter are used for the calculation of the fluxes:

1. temperature, relative humidity and pressure,
2. aerological sounding,
3. optical aerosol thickness,
4. optical parameters of aerosol near surface, that is, the values of the scattering and absorption coefficients, asymmetry factor (method 1),
5. aerosol optical parameters received in the clear-sky atmosphere from measurements of spectral transparency and of aureole (method 2).

Methods Used

Method 1 uses the scattering σ_o and absorption coefficients α_o of the surface aerosol at the wavelength $\lambda = 0.55$ μm (the extinction coefficient $\varepsilon_o = \sigma_o + \alpha_o$). The Angstrom exponent, received from the spectronephelometer data, is used for the determination of the scattering coefficient of the surface aerosol at the other wavelengths. The knowledge of the total optical aerosol thickness at $\lambda = 0.55$ μm, averaged for some period, allows us to build its vertical profile as follows: the measured values of the surface aerosol optical parameters are used for boundary layer calculation. The optical characteristics of continental aerosol model [1] are used for the altitudes above the boundary layer.

In method 2, described in detail in [2], the data for the aerosol total optical thickness, measured in the spectral region 0.41 μm–0.87 μm and the observed clear-sky brightness in the solar aureole region are used for the retrieval the optical aerosol characteristics (the optical aerosol scattering thickness, single scattering albedo and total optical aerosol thickness in solar region 0.2–4.0 μm). The vertical distribution of optical aerosol thickness at the wavelength $\lambda = 0.55$ μm is determined by exponential law with the scale H = 1 km.

Results

Tables 1, 2, and 3 show the values of the integral up- and downward fluxes $Q_{\uparrow\downarrow}(z)$ and net fluxes $Q(z)=Q_{\downarrow}(z)-Q_{\uparrow}(z)$ of the solar radiation (W/m^2) at the earth surface (z = 0) and the top of the cloudless atmosphere ($z = \infty$). These fluxes are calculated with and without the aerosol component of the atmosphere by the methods 1 and 2 in the case of the surface albedo $A_S = 0.4$ [3]. Also the values of the observed downward solar fluxes at the earth surface are presented in the tables. This gives a possibility to compare between each other the calculated and observed fluxes coming to the earth surface. In the tables the values of ARF(0), ARF(∞) and ARF(0,∞) of the whole thickness of the atmosphere are also shown. Table 1 is based on the measurements during 1 March (14.00, 14.40, 15.00 hours). Tables 2 and 3 are based on the

Table 1. Aerosol radiative forcing (ARF) in the shortwave region of the spectra. March 1, 2001. (14.00–15.00). The integral fluxes of the solar radiation $Q_{\downarrow\uparrow}(z)$, Q(z) (W/m2). $Q(z) = Q_{\downarrow}(z)- Q_{\uparrow}(z)$.

				With Aerosol (τ = 0.154)					
March 1	**Without Aerosol**			**Method 1 (λ =0.55 μm: ε_o =0.13, α_0 = 0.017)**			**Method 2**		
Air Mass. Time	2.3681 14.00	2.6081 14.40	2.7904 15.00	14.00	14.40	15.00	14.00	14.40	15.00
$Q_{\downarrow}(0)$ (observed $Q_{\downarrow}(0)$)	452.1 (435.6)	405.1 (381.2)	375.0 (352.2)	420.7	374.2	344.5	429.5	382.4	352.3
$Q_{\uparrow}(0)$	180.9	162.0	150.0	168.3	149.7	137.8	171.8	153.0	140.9
Q(0)	271.2	243.1	225.0	252.4	224.5	206.7	257.7	229.4	211.4
$Q_{\downarrow}(\infty)$	576.4	523.4	489.2	576.4	523.4	489.2	576.4	523.4	489.2
$Q_{\uparrow}(\infty)$	213.2	194.5	182.4	211.8	193.8	182.3	220.3	202.1	190.2
$Q(\infty)$	363.2	328.9	306.8	364.6	329.6	306.9	356.1	321.3	299.0
ARF(0) = $Q_{aer}(0)$ - Q(0)				**-18.8**	**-18.6**	**-18.3**	**-13.5**	**-13.7**	**-13.6**
ARF(∞) =$Q_{aer}(\infty)$ - Q(∞)				**1.4**	**0.7**	**0.1**	**-7.2**	**-7.6**	**-7.8**
ARF(∞) - ARF(0)				**20.2**	**19.3**	**18.4**	**6.3**	6.1	**5.8**

Table 2. ARF in the shortwave region of the spectra. March 6, 2001. (14.00–15.00). The integral fluxes of the solar radiation $Q_{\downarrow\uparrow}(z)$, $Q(z)$ (W/m2). $Q(z)= Q_{\downarrow}(z)- Q_{\uparrow}(z)$.

March 6	Without Aerosol			With Aerosol (τ = 0.050)					
				Method 1 (λ =0.55 μm: ε_o =0.042, α_0 = 0.0056)			Method 2		
Air Mass. Time	2.2239 14.00	2.3631 14.30	2.587 15.00	14.00	14.30	15.00	14.00	14.30	15.00
$Q_{\downarrow}(0)$ (observed $Q_{\downarrow}(0)$)	483.5 (472.5)	451.4 (436.0)	407.2 (387.1)	474.0	441.8	397.7	476.4	444.2	399.3
$Q_{\uparrow}(0)$	193.4	180.5	162.9	189.6	176.7	159.1	190.8	177.7	159.9
$Q(0)$	290.1	270.9	244.3	284.4	265.1	238.6	285.6	266.5	239.4
$Q_{\downarrow}(\infty)$	613.7	577.6	527.6	613.7	577.6	527.6	613.7	577.6	527.6
$Q_{\uparrow}(\infty)$	225.2	212.6	195.0	224.9	212.5	195.2	227.1	214.7	197.4
$Q(\infty)$	388.5	365.0	332.6	388.8	365.1	332.4	386.8	362.9	330.2
ARF(0) = $Q_{aer}(0)$ - Q(0)				**-5.7**	**-5.8**	**-5.7**	**-4.5**	**-4.4**	**-4.9**
ARF(∞) = $Q_{aer}(\infty)$ -Q(∞)				**0.3**	**0.1**	**-0.2**	**-1.7**	**-2.1**	**-2.4**
ARF(∞) - ARF(0)				**6.0**	**5.9**	**5.9**	**2.8**	**2.3**	**2.5**

Table 3. ARF in the shortwave region of the spectra. March 6, 2001. (14.00–15.00). The integral fluxes of the solar radiation $Q_{\downarrow\uparrow}(z)$, $Q(z)$ (W/m2). $Q(z)= Q_{\downarrow}(z)- Q_{\uparrow}(z)$.

March 26	Without Aerosol			With Aerosol (τ = 0.09)					
				Method 1 (λ =0.55 μm: ε_o =0.056, α_0 = 0.0078)			Method 2		
Air Mass. Time.	1.6828 14.00	1.7159 14.30	1.7796 15.00	14.00	14.30	15.00	14.00	14.30	15.00
$Q_{\downarrow}(0)$ (observed $Q_{\downarrow}(0)$)	662.6 (643.7)	648.4 (626.1)	622.5 (595.4)	643.8	629.5	603.5	650.5	636.1	610
$Q_{\uparrow}(0)$	265.	259.3	249.	257.5	251.8	241.4	260.2	254.4	244
$Q(0)$	397.6	389.1	373.5	386.3	377.7	362.1	390.3	381.7	366
$Q_{\downarrow}(\infty)$	811.1	795.5	767.	811.1	795.5	767.0	811.1	795.5	767
$Q_{\uparrow}(\infty)$	293.9	288.5	278.8	290.4	285.2	275.8	296.5	291.3	281.7
$Q(\infty)$	517.2	507.	488.2	520.7	510.3	491.2	514.6	504.2	485.3
ARF(0) = $Q_{aer}(0)$ - Q(0)				**-11.3**	**-11.4**	**-11.4**	**-7.3**	**-7.4**	**-7.5**
ARF(∞) = $Q_{aer}(\infty)$ -Q(∞)				**3.5**	**3.3**	**3.0**	**-2.6**	**-2.8**	**-2.9**
ARF(∞) - ARF(0)				**14.8**	**14.7**	**14.4**	**4.7**	**4.6**	**4.6**

measurements during March 6 and 26 (14.00, 14.30, 15.00 hours). The estimates of ARF are obtained with the account of the measured optical parameters of the surface aerosol (method 1) and received optical aerosol characteristics by the solution of the inverse problem in the cloudless days (method 2). In Tables 1 through 3 the results of the ARF calculation received by using the above methods with the values of the optical thickness of the aerosol accordingly τ = 0.154, 0.050, 0.090 are presented. The day March 6 is characterizing by the small aerosol content in the atmosphere. The single scattering albedo of the surface aerosol ω at wavelength λ = 0.55 μm (ω = 0.865, method 1) and the same value determined by the method 2 related to aerosol averaged with height (ω = 0.975, the complex index of refraction of the particles according to the aerosol model [4]) differ essentially.

The tables show that the ARF(∞) values obtained by the methods 1 and 2 have, as a rule, different signs. This is due to that the aerosol absorption coefficients measured by method 1 differ from the ones used in method 2 where they are taken from the model [4]. The presented estimates of ARF(z) are obtained at A = 0.4.

From tables it can be seen, that the account of the aerosol component leads to the results: the earth surface is cooled (ARF(0)<0), the surface-atmosphere system is heated or cooled (ARF(∞)>0 or ARF(∞)<0), the whole thickness of the atmosphere is heated (ARF(∞)> ARF(0)).

At Figure 1 the ARF values of the surface-atmosphere system in dependence on the values of aerosol single scattering albedo and albedo of the underlying surface A for March 26, 2001 (14.00), are presented. It is seen that the aerosol can create significant changes in ARF(∞) due to warming caused by increased absorption of solar radiation in the winter atmosphere.

Conclusions

The degree of the aerosol effect on the radiation balance is determined mainly by the values of the aerosol single scattering albedo, the surface albedo and, certainly, the optical aerosol thickness. For the ZCAREX-2001, our analysis indicates that the aerosol decreases naturally the influx of the solar energy at the earth surface with ARF(0) between –3.9 and –18.8 W/m^2. At the same time the surface-atmosphere system is cooled or is heated first of all in dependence on the value of single scattering albedo of the aerosol with ARF(∞) between –7.8 and 1.4 W/m^2. The whole thickness of the atmosphere is heated with (ARF(∞)-ARF(0)) between 1.9 and 20.2 W/m^2.

References

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