# Aerosol Radiative Forcing During Spring-Summer 2002 from Measurements at IAP Scientific Station Near Moscow

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## Introduction

Aerosol Radiative Forcing (ARF) is estimated for spring-summer conditions from measurements during the Cloud-Aerosol-Radiation Experiment in 2002 (ZCAREX-2002) at the Zvenigorod Scientific Station (55°42'N, 36°46'E) of the A. M. Obukhov Institute of Atmospheric Physics Russian Research Center (IAP ZSS). The first phase of coordinated measurements was in March-April 2002. The second active phase in July-September 2002 was related to peatbog and forest fires near Moscow. Similar fires with smoky atmosphere were occurred in this region 30 years ago in summer 1972 (also, as in 2002, during formation of El-Niño). 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 in the clear-sky conditions.

## Data Used

The following data of atmospheric characteristics observed during spring-summer 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,

5. satellite data.

## Methods Used

The method for ARF calculation uses the scattering and absorption coefficients of the surface aerosol at the wavelength $\lambda = 0.55$ µm. The Angstrom exponent, received from the spectronephelometer data, is used for the determination of the surface aerosol scattering coefficient at the other wavelengths. The knowledge of the total optical aerosol thickness at $\lambda = 0.55$ µm observed during the same period makes possible to find its vertical profile as follows. The measured values of the surface aerosol optical parameters are used for atmospheric boundary layer. The optical characteristics of continental aerosol model (WCP 1986) are used for the altitudes above the boundary layer. The method of the calculation of the integral solar fluxes is taking into account molecular scattering, the scattering and absorption of aerosol, and the absorption of atmospheric gases $H_2O$, $CO_2$, $O_2$, $O_3$ (Gorchakova 2000). Solar radiation fluxes parameterized as in (Gorchakova 2000) are compared with the fluxes estimates received by the online calculator of integral solar fluxes ([CSIF] tool available at: http://www1.imp.kiae.ru/ csif). The CSIF uses the Monte Carlo radiative transfer algorithm together with line-by-line technique of gaseous absorption.

## Results

The total aerosol optical depth $\tau$ in spring was between 0.03 and 0.34, while during the summer fires the values of $\tau$ were considerably larger. Table1 shows the values of the integral up- and down-welling and also net fluxes of the solar radiation $Q_{\downarrow\uparrow}(z)$ (W/m$^2$) at the surface (z = 0) and the top of the cloudless atmosphere ($z = \infty$) calculated with and without the aerosol. In this case, the surface albedo $A_S = 0.2$. The processing of the satellite data shows that in spring and in summer the following values of the surface albedo $A_S = 0.06$ at ultraviolet- (UV), visible- (VIS) ranges, and $A_S = 0.22$ at BIK- range of the solar radiation can be used. Table 1 is based on the measurements at March 19 (14.30 Local Standard Time [LST]). The estimates of ARF were received according to (Gorchakova 2000, CSIF online tool) at the value of the aerosol optical thickness $\tau = 0.13$ at 14.30 LST.

**Table 1**. The integral fluxes of the solar radiation $Q_{\downarrow\uparrow}(z)$, $Q(z) = Q_\downarrow(z) - Q_\uparrow(z)$. (W/m$^2$). ARF in the shortwave range. $ARF(z) = Q_{aer}(z) - Q(z)$. Albedo of the surface $A_S = 0.2$

| March 19, 2002 (14.30 LST) | Method (Gorchakova 2000) ($\varepsilon_{0.55\mu m}=0.14$, $\alpha_{0.55\mu m}= 0.02$) | | CSIF (online tool) | |
|---|---|---|---|---|
| | Without Aerosol | With Aerosol ($\tau = 0.13$) | Without Aerosol | With Aerosol ($\tau = 0.13$) |
| $Q_\downarrow(0)$ | 526 | 500 | 531 | 508 |
| $Q_\uparrow(0)$ | 105 | 100 | 106 | 102 |
| $Q(0)$ | 421 | 400 | 425 | 406 |
| $Q_\downarrow(\infty)$ | 673 | 673 | 673 | 673 |
| $Q_\uparrow(\infty)$ | 144 | 153 | 140 | 150 |
| $Q(\infty)$ | 529 | 521 | 533 | 524 |
| $ARF(0) = Q_{aer}(0)-Q(0)$ | -20 | | -20 | |
| $ARF(\infty) = Q_{aer}(\infty)-Q(\infty)$ | -9 | | -9 | |
| $ARF(\infty)-ARF(0)$ | 11 | | 10 | |

In spring, the values of ARF (0) at the surface were in the range from –45 to –6 $Wm^{-2}$ (14 ÷ 15 LST). The appropriate values of ARF for the whole atmosphere (ARF (∞)–ARF (0)) were between 4 $Wm^{-2}$and 28 $Wm^{-2}$. The values of ARF (∞) at the TOA were found in the range from -17 $Wm^{-}$2 to -2 $Wm^{-2}$. These results differ from estimates of previous winter-spring experiment ZCAREX-2001. It was remarkably warmer in March 2002 in comparison with March 2001, and it was practically no snow cover during the indicated period. Besides, the aerosol in 2001 had a larger amount of black carbon.

The total aerosol optical depth $\tau$ during the summer fires was between 0.3 and 1.4. It was noted that aerosol was only weakly absorbing. The single scattering albedo changed between 0.96 and 0.98. The Angstrom exponent was larger in July and August (about 1.7) than it was in September (<1.2). Figures 1 and 2 show the values of the integral downward solar fluxes at the surface observed and calculated for July 30 and August 15 (13.30 ÷ 18.00 LST). The differences between the average values of observed and calculated fluxes are less than 15 $W/m^2$.

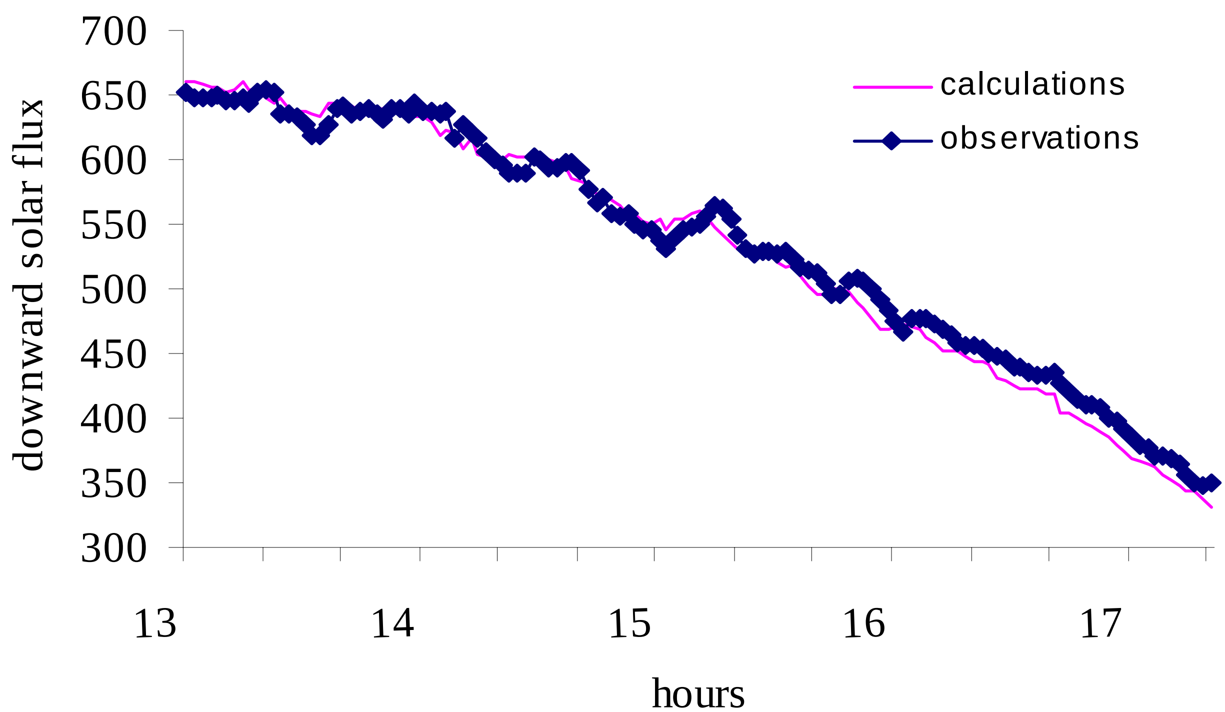


**Figure 1**. July 30, 2002, integral observed and calculated downward solar fluxes at the surface ($W/m^2$).

Figures 3-6 are based on the measurements at March 19, July 30, August 15, and September 6. Figure 3 shows the optical aerosol thickness $\tau$. According to Figure 3 the values of the optical aerosol thickness were in the following ranges: $0.11 \le \tau \le 0.13$ on March 19, $1.0 \le \tau \le 1.4$ on July 30, $0.4 \le \tau \le 0.5$ on August 15, $0.8 \le \tau \le 1.0$ on September 6. At Figures 4 through 6 ARF at the surface, at the top of the atmosphere (TOA) and the whole atmosphere are presented. The estimates of ARF ($W/m^2$) are obtained taking into account the optical parameters of surface aerosol measured during 12.00 ÷ 18.00 LST. The

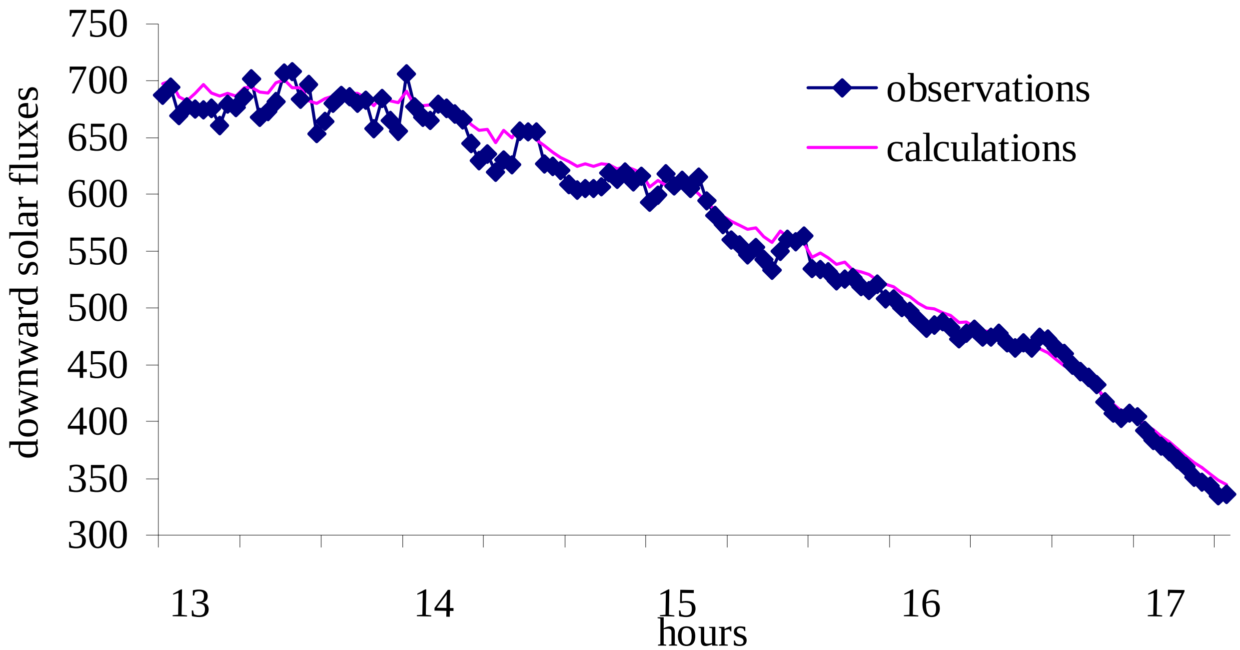


**Figure 2**. August 15, 2002, integral observed and calculated downward solar fluxes at the surface, W/m$^2$.

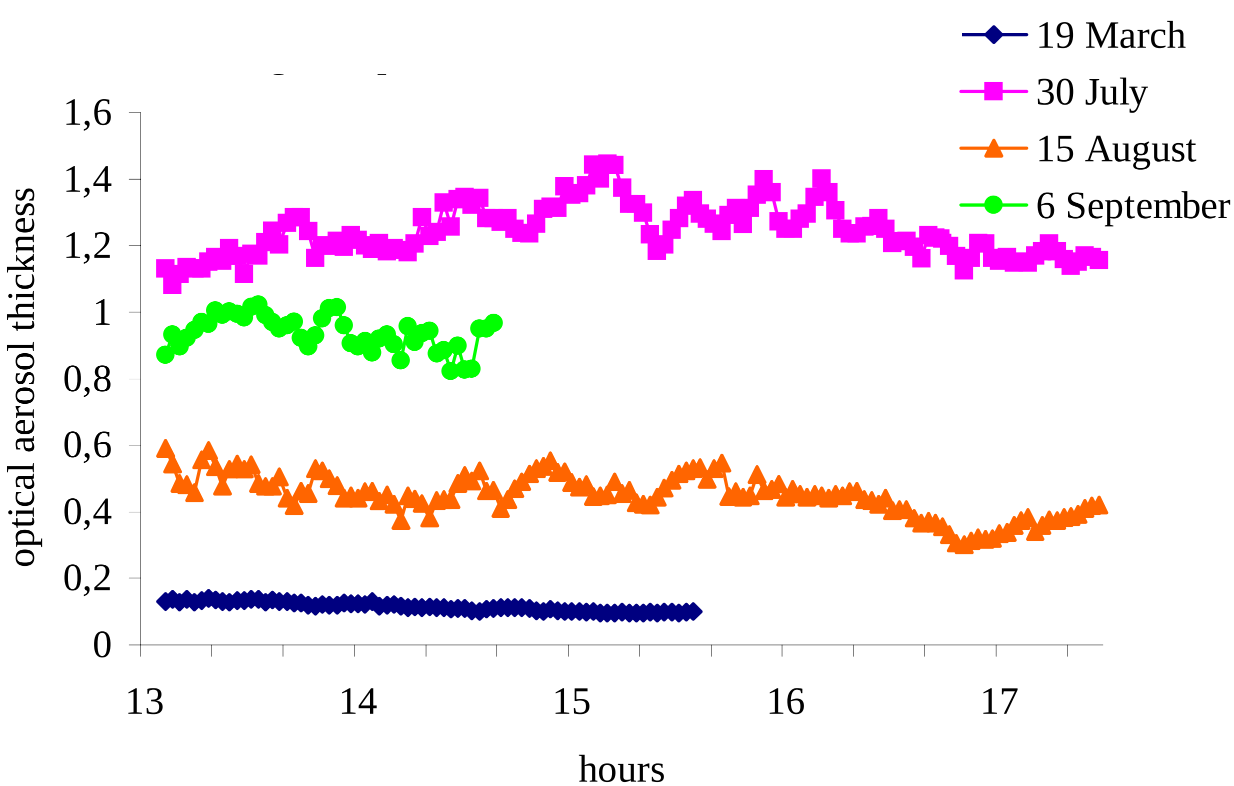


**Figure 3**. Optical aerosol thickness $\tau$ at $\lambda$ = 0.55.

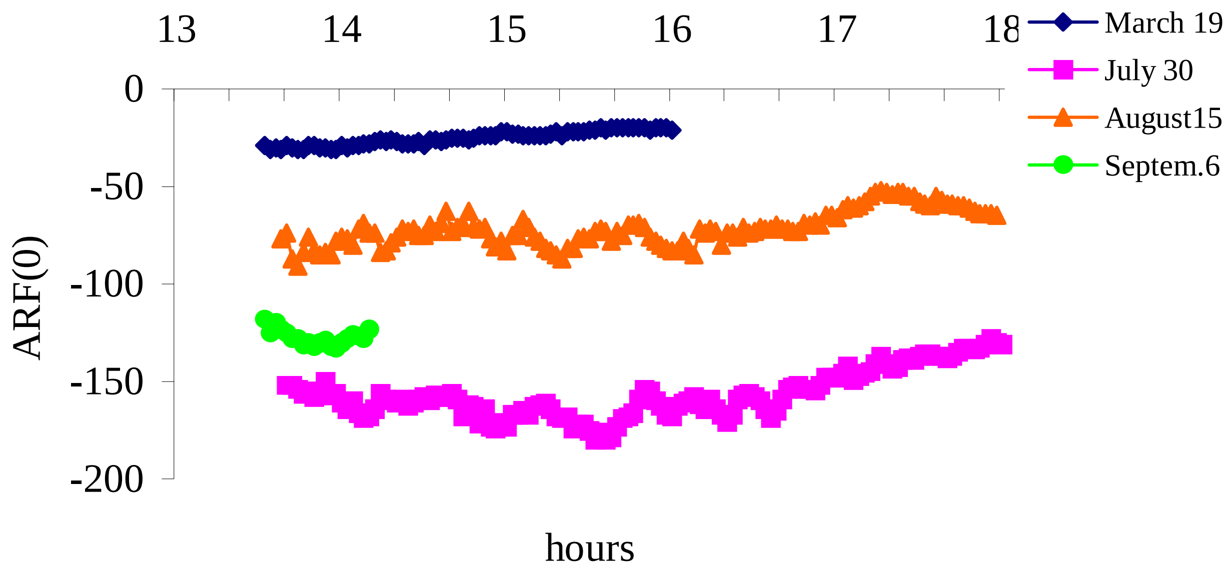


**Figure 4**. ARF at the surface ARF(0), W/m$^2$, March 19, July 30, August 15, and September 6, 2002.

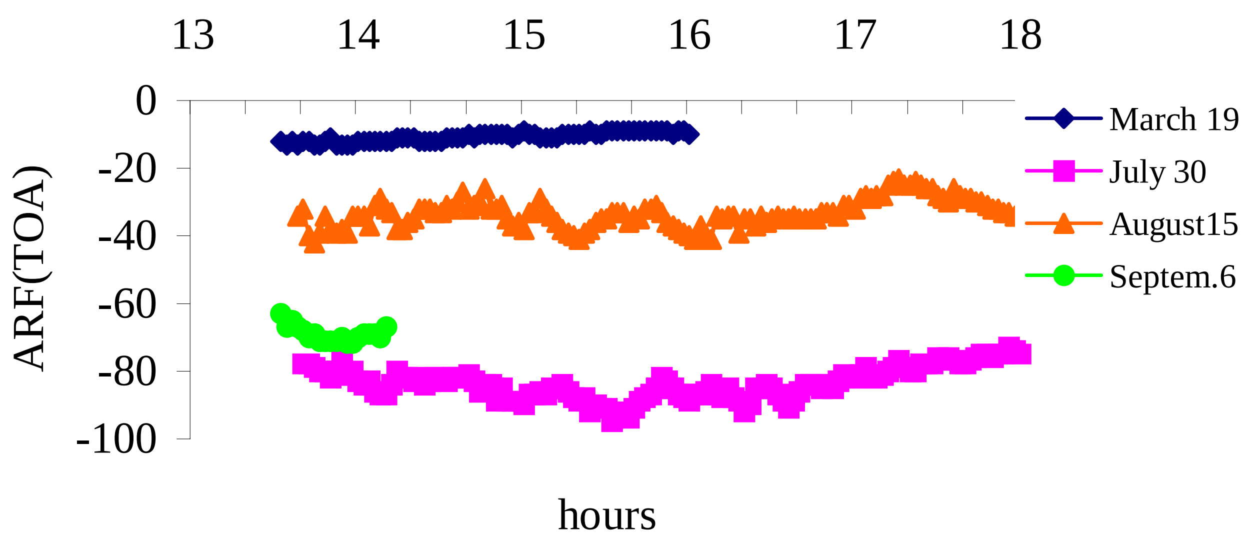


**Figure 5**. ARF at the TOA ARF, W/m$^2$, March 19, July 30, August 15, and September 6, 2002.

results of the ARF calculation were obtained for $\tau$ observed 19 March during 13.30 ÷ 16.00 LST, July 30 and August 15 during 13.40 ÷ 18.00 LST, 6 September during 13.40÷14.10 LST. The results of the calculations show that for March 19, ARF(0) varies between –30 W/m$^2$ and –20 W/m$^2$, ARF($\infty$) - between -12 W/m$^2$ and –9 W/m$^2$, (ARF($\infty$)–ARF(0)) – between 11 W/m$^2$ and 18 W/m$^2$. Correspondingly, for July 30, the values of ARF(0) vary between –180 W/m$^2$ and –127 W/m$^2$, ARF($\infty$) - between –94 W/m$^2$ and -70 W/m$^2$, (ARF($\infty$)-ARF(0)) - between 57 W/m$^2$ and 86 W/m$^2$.

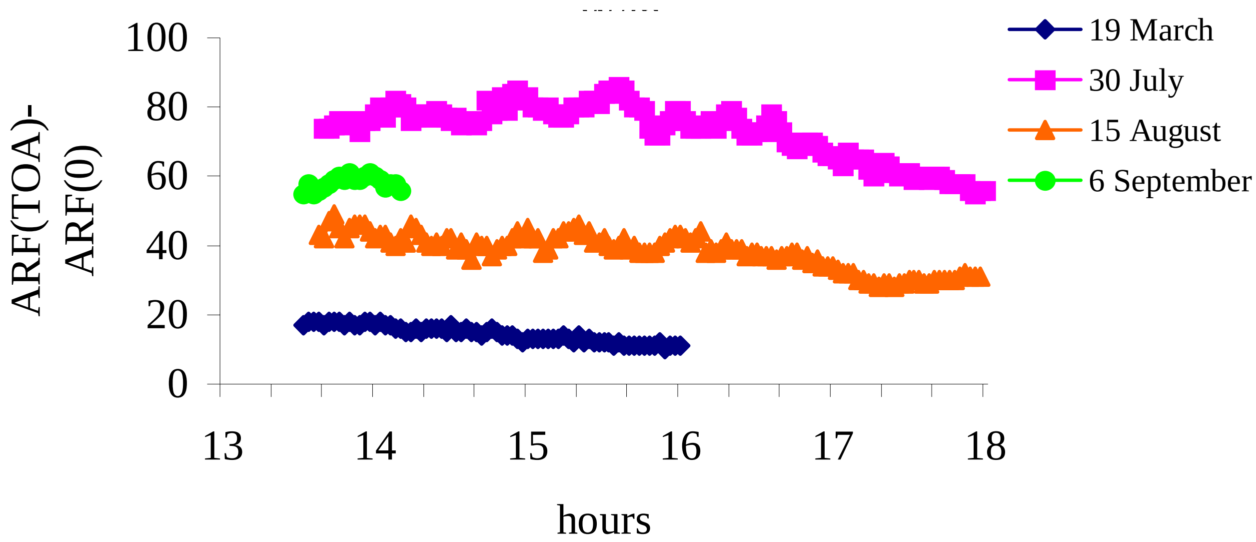


**Figure 6**. March 19, July 30, August 15, and September 6, 2002, ARF of the whole atmosphere ARF(TOA) – ARF(0), W/m$^2$.

## Conclusions

The effect of weakly absorbing aerosol on the radiation balance is mainly determined by the values of its optical thickness. For the ZCAREX-2002 our analysis indicates that in spring the aerosol decreases the net flux of the solar energy at the surface with the values of ARF(0) between -45 W/m$^2$ and -6 W/m$^2$. The surface-atmosphere system is cooling with the values of ARF(∞) between -17 W/m$^2$ and -2 W/m$^2$. The whole atmosphere is heating with the value (ARF(∞)-ARF(0)) between 4 W/m$^2$ and 29 W/m$^2$. The absolute values of ARF(0) and ARF(∞) in the smoky atmosphere during summer 2002 were up to few times larger compared to those obtained for March 2002. In the analyzed cases in the smoky atmosphere, the values of ARF(0) are between -180 W/m$^2$ and -54 W/m$^2$. The values of ARF( ∞) vary from -94 W/m$^2$ until -26 W/m$^2$. The whole thickness of the atmosphere heats with (ARF(∞)-ARF(0)) between 28 W/m$^2$ and 86 W/m$^2$.

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