SCAR-B PROCEEDINGS

Collection of papers presented at the Fortaleza, Brazil workshop, November 1996

V.W.J.H.Kirchhoff, editor

TRANSTEC EDITORIAL

Dados Internacionais de Catalogação na Publicação (CIP)
(Câmara Brasileira do Livro, SP, Brasil)

SCAR-B (1996 : Fortaleza)
SCAR-B : smoke/sulfate, clouds and radiation-Brasil : procedings. -- São José dos Campos, SP : Transtec, 1996.

1. Atmosfera - Pesquisa - Congressos 2. Geofísica 3. Particulados radioativos 4. Química atmosférica I. Título.

96-5110 CDD-551.5072

Indices para catálogo sistemático:

1. Atmosfera : Pesquisa : Congressos 551.5072
2. Congressos : Atmosfera : Pesquisa 551.5072

ISBN 85-85417-09-9

TRANSTEC EDITORIAL

On derivation of the smoke single-scattering albedo using radiative transfer calculations and sunphotometer and broad band irradiance measurements made in Cuiaba on 27 and 28 August 1995.

T.A.Tarasova
Centro de Previsao de Tempo e Estudos Climaticos/Instituto National de Pesquisas Espaciais, Cachoeira Paulista, Sao Paulo, Brazil

T.F. Eck, B.N. Holben
NASA Goddard Space Flight Center, Greenbelt, Maryland

A. Setzer
Instituto National de Pesquisas Espaciais, Sao Jose Dos Campos, Sao Paulo, Brazil

Abstract. To calculate the photosynthetically active radiation (PAR) and total solar irradiance at the Earth's surface the optical model of the clear sky atmosphere was suggested taking into account the smoke loading in the layer from 0 km through 4 km. This model is based on the standard atmosphere profiles of the meteorological elements and the optical parameters of the continental and stratosphere aerosol types [WCP-112, 1986]. We employed the vertically inhomogeneous Delta-Eddington radiation code, where the molecular scattering, absorption and scattering by aerosol particles, absorption by water vapor and ozone are taken into account. The columnar aerosol optical thickness was retrieved from the sunphotometer measurements at the 7 wavelengthes from 339 through 1021 nm [Holben et al., 1996].

To derive the single-scattering albedo ω_0 of the smoke particles in the atmospheric layer 0...4 km we compared the computation results with the broad band irradiance measurements at the Earth's surface [Eck et al., 1996] during cloudless conditions on 27 and 28 August 1995 in Cuiaba. The values of ω_0=0.84...0.86 at the wavelength 550 nm were estimated from PAR observations. The single scattering albedo values derived from the total solar irradiance measurements have a wider range of incertainty. The probable causes of these discrepancies are discussed.

1. Introduction.

The absorption of the solar radiation by aerosols in the Earth's atmosphere is governed by the aerosol optical thickness τ and the single-scattering albedo ω_0 determined at each wavelength λ of solar spectrum and for all atmospheric layers. As a rule, for climate studies the aerosol single-scattering albedo is calculated from the Mie theory using microphysical parameters measured in situ [Shettle and Fenn, 1976; Blanchet and List, 1983; Sokolik and Golitsyn, 1992]. The reported climotological values of the aerosol single-scattering albedo need additional verification according to the significant discripancies of the results for the same aerosol type [Sokolik and Golitsyn,1992]. Therefore, the methods of the satellite and aircraft remote sensing of the aerosol absorption were suggested [Kaufman, 1987; Kaufman et al., 1992]. The columnar average single-scattering albedo for the visible region of solar spectrum was estimated as ω_0=0.9±0.01 over the forest fire smoke and ω_0=0.94±0.04 over the industrial regional haze. The method of the derivation of ω_0 from the simultaneous measurements of the direct beam and total solar irradiance at the ground [Tarasova et al., 1992] was applyed to the long-term radiation observations performed at the Meteorology Observatory of Moscow State University during summer seasons from 1955 through 1991. The columnar and solar spectrum average single-scattering albedo ω_0=0.9±0.2 was determined for the total period of observations. The values ω_0=0.8...0.9 are for the period of large biomass burning near Moscow on August 1972 and ω_0=0.95 is for the periods of the large volcanic eruptions [Gorbarenko, 1996]. The values ω_0=0.9...0.95 were found during the dust radiation field experiment in Dushanbe region (Central Asia, Former Soviet Union) on September 1988 [Tarasova et al., 1992]. Nevertheless, there are uncertainties in the evaluation of the accuracy of this methods and their ability to determine the spatial and temporal variations of the aerosol single scattering albedo.

2. Parameters of the atmosphere adopted for use in radiation calculations.

The molecular scattering, absorption and scattering by aerosol particles, absorption by water vapor and ozone are taken into account in 21 homogeneous layers. The profile of the molecular scattering is in accordance with Pendorf's formula [1957]. To calculate the water vapor and ozone effective amount in the layers we utilized the model of Tropical standard atmosphere [McClatchey et al., 1972]. The vertical profiles of the background aerosol optical parameters (optical thickness, single-scattering albedo and asymmetry factor of the phase function) were adopted according to Convective model [WCP-112,1986]. This model presents the exponential profile of the aerosol extinction coefficient at the wavelength 550 nm in the layer 0...4 km: $\varepsilon=\varepsilon_0(-z/1)$, where $\varepsilon_0=0.2$ is the extinction coefficient at the ground. The columnar aerosol optical thickness at 550 nm of the background aerosol model is 0.219.

We adopted for use in computations the spectral dependence of aerosol optical parameters suggested for the Stratosphere and Continental aerosol types [WCP-112,1986] . The single-scattering albedo at 550 nm is 0.9999 for the first type and 0.98 for the second one. Fig. 1 presents the spectral dependence of ω_0. We used the broad band ozone absorption coefficients reported by Briegleb [1992]. The surface albedo is 0.06 in the visible spectrum and 0.28 in the near infrared one according to medium/tall grassland and woodland type of the surface [Briegleb, 1992] and low density residential type [Brest, 1987].

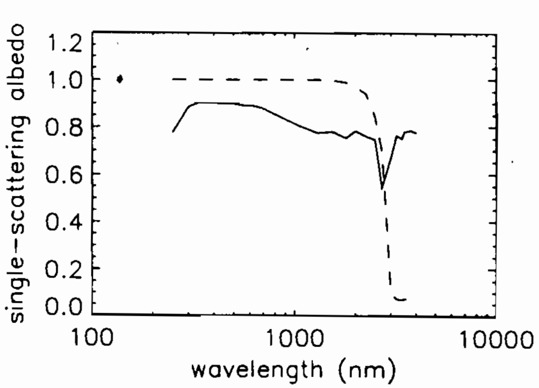

Fig.1 The spectral dependence of the single-scattering albedo of Continental (solid curve) and Stratosphere aerosol models (dashed curve) [WCP-112, 1986].

To calculate the radiative transfer we employed the vertically inhomogeneous Delta-Eddington code [Joseph et al.,1976]. The absorption by water vapor in the scattering aerosol atmosphere was computed using mean photone path method [Tarasova, 1996] and the water vapor transmission functions obtained for 7 water vapor absorption bands [Fomin et al.,1993] on the base of AFGL HITRAN 1986 compilation [Rothman at al., 1987]. The transmission of solar radiation was calculated for 19 spectral intervals over the solar spectrum from 285 through 4000 nm, weighted by the solar spectral irradiance at the atmosphere top [WCRP-7, 1986] and summed to produce the photosythetically active (PAR) and total solar radiation at the ground.

3. Sunphotometer and broad band irradiance data measurements.

The Cimel sunphotometer measurements of the direct beam solar radiation at the wavelengthes 339, 379, 437, 498, 669, 871, 1021 nm were made in Cuiaba on August 27, 28 1996 every 15 minutes [Holben et al., 1996]. The cloudless homogeneous aerosol atmosphere was observed during these days. Table 1 presents the retrieved columnar aerosol optical depth at the wavelength 498 nm averaged over half an hour from 11h45' through 14h15' Local Standard Time (LST). Note, that the first day was more hazy than the second one. The cosine of the solar zenith angle was calculated according to Iqbal [1983].

Table 1. The columnar aerosol optical thickness τ at 498 nm obtained on August 27 and August 28 and the cosine of solar zenith angle $\cos\theta$ at different Local Standard Time (LST).

	August 27		August 28	
LST	$\cos\theta$	τ	$\cos\theta$	τ
11h45m	0.904	0.824	0.906	0.495
12h15m	0.894	0.838	0.899	0.516
12h45m	0.872	0.863	0.875	0.540
13h15m	0.833	0.885	0.835	0.525
13h45m	0.778	0.905	0.78	0.503
14h15m	0.71	0.896	0.711	0.494

The broad band radiation measurements were made at INPE Cuiaba at 1 minute sampling interval [Eck et al., 1996]. The total solar irradiance (285-2800 nm) was measured with Eppley Precision Spectral Pyranometer (PSP) and PAR (400-700 nm) was measured with Skye-Probetech PAR Energy sensor (SKE-510). We averaged these data over the same half an hour intervals from 11h45'LST through 14h15'LST as was done for aerosol optical thickness. The results are shown in Fig.2 and Fig.3.

4. Comparison of the broad band solar irradiance measurements with the calculation results.

To perform the radiative transfer calculations we added the smoke aerosol to the layer from the surface through the height 4 km [Kaufman et al., 1992]. The value of the aerosol extinction coefficient at the ground ε_0 was chosen to obtain the total aerosol optical thickness retrieved by sunphotometer. The columnar aerosol optical thickness at the middle of each spectral interval was determined interpolating the results of sunphotometer measurements at 7 wavelengthes. To calculate the sensitivity of the solar rradiance to the single-scattering albedo of smoke particles we changed the value of ω_0 at the wavelength 550 nm when it's relative spectral dependence remained the same.

the radiative transfer equation have got an error that is equal 2% approximately. So, we can't determine ω_0 more precisely performing computations with the smaller values. Therefore, to estimate the single-scattering albedo another method was employed assuming that ω_0 varied slightly during two days. Table 3 presents the range between PAR measured on August 27 and August 28 at the same LST. The PAR difference calculated for ω_0=0.84...0.86 is in a good agreement with the measured data .

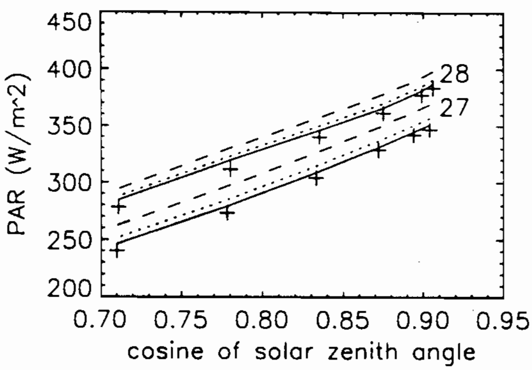

Fig.3 Photosynthetically active radiation (PAR): pluses are the measured data, the curves are the calculation results for ω_0=0.84 at 550 nm (solid curve), for ω_0=0.86 (dotted curve) and for ω_0=0.9 (dashed curve). The upper group of curves and marks is for August 28, the lower group is for August 27.

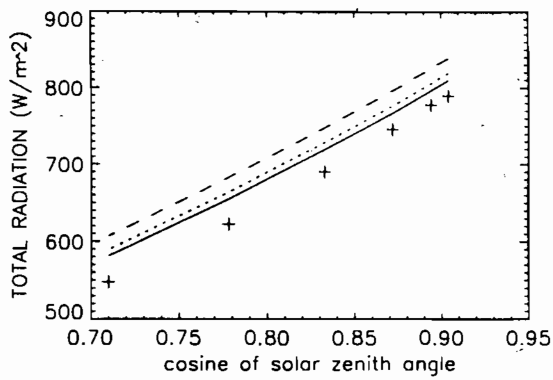

Fig 4. Total solar irradiance on August 27: pluses are measured data,.the curves are for calculation results for ω_0=0.84 at 550 nm (solid curve), for ω_0=0.86 (dotted curve) and for ω_0=0.9 (dashed curve).

Table 2. The discrepancies between the calculated and measured PAR data (W/m^2) on August 27 and 28. Computations are for smoke single-scattering albedo ω_0= 0.84, 0.86 at 550 nm.

	ω_0=0.84		ω_0=0.86	
LST	August 27	August 28	August 27	August 28
11h45m	4.3	3.6	10.0	7.4
12h15m	2.9	4.0	8.6	7.8
12h45m	2.4	4.0	8.2	8.3
13h15m	4.6	6.1	10.3	9.9
13h45m	5.8	7.9	11.4	11.4
14h15m	4.0	6.3	11.2	9.5

Table 3. The range (W/m^2) between the broad band irradiance on August 27 and 28 at the same LST. Measured (M)and calculated (C) values of PAR and total solar flux changes are shown. Computations are for ω_0=0.84, 0.86.

	PAR			TOTAL		
LST	M	C	C	M	C	C
		ω_0=0.84,	0.86		ω_0=0.84,	0.86
11h45m	36.5	35.8	29.5	45.3	53.6	44.2
12h15m	35.1	36.2	30.1	44.2	55.1	46.2
12h45m	32.9	34.9	28.9	39.9	52.4	43.6
13h15m	35.9	37.4	31.3	48.4	55.5	46.1
13h45m	38.2	40.3	33.6	53.4	59.8	50.1
14h15m	38.0	38.3	32.0	52.1	56.7	47.5

Fig. 2 presents PAR calculated with different smoke single-scattering albedo ω_0=0.84,0.86,0.9 at 550 nm. The discrepancies between measured and calculated values are given in Table 2. The relative difference for the cases with ω_0=0.84,0.86 is less than 5% and can be explained by many causes except the influence of the single-scattering albedo, such as the errors of the Delta-Eddington technique and sensor measurements, uncertainties in our knowledge of optical and physical properties of the atmosphere and so on. Even the precise numerical methods of the solution of

The comparison of the computed and measured total solar irradiance data presented in Fig.3 is much more complicated due to use of the approxomate method to calculate water vapor absorption in the scattering aerosol atmosphere, to the lack of the sunphotometer measurements in the near infrared region of solar spectrum and to the uncertainties in our knowledge of the spectral dependence of ω_0 in the near infrared region of solar spectrum, etc. Therefore, the relative difference between the calculated and measured data increases to 2.5...6.4% for ω_0=0.84 and to 5.7...10.9% for ω_0=0.9. The absolute difference is 20...50

W/m^2 and has to be discussed. One of the possible explanations is the underestimate of the water vapor absorption in the scattering aerosol atmosphere by approximate radiation code . The reference line-by-line calculations could brighten up this question.

Table 4. The discrepancies between calculated and measured total solar irradiance (W/m^2) on August 27 and 28. Computations were performed with the smoke single-scattering albedo 0.84, 0.9 at 550 nm.

	ω_0=0.84		ω_0=0.9	
LST	August 27	August 28	August 27	August 28
11h45m	20.2	28.5	48.9	47.8
12h15m	18.2	29.7	47.6	49.6
12h45m	20.9	33.4	49.9	53.6
13h15m	29.2	36.3	57.9	55.6
13h45m	32.3	38.7	60.0	56.7
14h15m	34.0	38.6	59.7	55.1

The difference between the total solar irradiance on August 27 and 28 at the same LST is given in Table 3. To obtain the good agreement with the measured range we have to use ω_0=0.87...0.93 for computations. To obtain the good agreement with the absolute values of the measured total solar irradiance we have to adopt ω_0=0.84 or less. This discrepancy shows that there are some gaps in the radiation scheme dealing with the calculations in the near infrared region of solar spectrum. The detailed comparisons with the reference line-by-line techniques and with measured data could help to reveal the main causes of the discrepancy. Note that for studies of climate variations it is needed to calculate precisely the changes of solar radiation at the atmosphere boundaries due to aerosol pollution.

REFERENCES.

Brest C.L. Seasonal albedo of an urban/rural landscape from satellite observations, J. Climate and Appl. Met., 26 (9), 1169-1187, 1987.

Briegleb, B.P., Delta-Eddington approximation for solar radiation in the NCAR Community climate model, J. Geophys. Res., 97 (D7), 7603-7612, 1992.

Blanchet, J.-P. and R. List, Estimation of optical properties of Arctic Haze using a numerical model, Atmosphere-Ocean, 21 (4), 444-465,1983.

Eck, T.F., B.N. Holben, and I.Slutsker, Measurements of irradiance attenuation and calculation of aerosol single-scattering albedo for biomass burning aerosols during SCAR-B, SCAR-B Science Symposium, Fortaleza, Brazil, 1996.

Fomin, B.A., S.V.Romanov, A.N. Trotsenko, Line-by-line benchmark calculations of solar radiation transfer parameters in pure cloudless atmosphere. Izvestiya-Atmospheric and Oceanic Physics,29 (1), 57-66. 1993.

Gorbarenko E.V., Spatial and temporal variation of atmospheric aerosol optical thicknes on the territory of the former Soviet Union., Ph.D. Thesises. Moskva, 20 p., 1995.

Holben, B.N., A. Setzer, T.F. Eck, A. Pereira and I.Slutsker, Effect of dry season biomass burning on Amazon basin aerosol concentrations and optical properties, J.Geophys.Res., 101, 19,465-19,481, 1996.

Joseph, J.H., W.J.Wiskombe and W.A. Weinman, The Delta-Eddington approximation for radiative flux transfer, J. Atmos. Sci., 33, 2452-2459, 1976.

Kaufman, Y.J., Satellite sensing of aerosol absorption, J. Geophys. Res., 92 (D4), 4307-4317, 1987.

Kaufman, Y.J., A. Setzer, D. Ward, D. Tanre, B.H. Holben, P. Menzel, M.C. Pereira, and R. Rasmussen, Biomass burning airborn and spaceborn experiment in the Amazonas (BASE-A),J. Geophys. Res.,97 (D13), 14,581-14,599, 1992.

McClatchey,R.A., R.W.Fenn, J.E.A.Selby, F.E.Volz and J.S.Garing, Optical properties of the atmosphere, third edition, AFCRL-72-0497, [NTISN 7318412], 108 p., 1972.

Pendorf, R., Tables of the refractive index for standard air and the Rayleigh scattering coefficient for the spectral region 0.2 and 20 mcm and their application to atmospheric optics. J. Opt. Soc. Amer., 47, 176-182, 1957.

Rothman, L.S., R.R.Gamashe, A.Goldman, L.R.Brown, R.A.Toth, H.M.Picket, R.L.Poynter, J.-M. Flaud, C.Camy-Peyret, A.Barbe, N.Husson, C.P.Rinsland M.A.H.Smith, The HITRAN database: 1986 edition, Appl. Opt.,26, 4058-4097, 1987.

Shettle, E.P. and R.W.Fenn, Models of the atmospheric aerosols and their optical properties. AGARD Conference ProceedingsN 183, Optical Propagation in the Atmosphere, [NTIS-AD-A028-615], 1976.

Sokolik, I.N. and G.S. Golitsyn, An investigation of the optical and radiative characteristics of dust aerosol. Izvestya, Atmospheric and oceanic physics, 28 (8), 593-600, 1992.

Tarasova, T.A., G.M. Abakumova, I.N. Plakhina, Determination of the absorbing properties of aerosol hase from measurements of direct and total integral solar radiation with a clear sky, Izvestiya-Atmospheric and Oceanic Physics, 28 (4), 288-294, 1992.

Tarasova T.A., Different versions of the Delta-Eddington approximation and the simultaneous calculation of the water vapor absorption in radiation codes for models. In: Proceedings of the International Radiation Symposium:current problems in atmospheric radiation, University of Alaska, Fairbanks, August 19-24, 1996.

World Climate Research Programme, A preliminary cloudless standard atmosphere for radiation computation, WCP-112, WMO/TD-No24, 53 p.,1986.

World Climate Research Programme, Revised instruction manual on radiation instruments and measurements, WCRP-7, WMO/TD No149, 135 p., 1986.