SEASONAL VARIATIONS OF SURFACE SOLAR IRRADIANCES UNDER CLEAR-SKIES AND CLOUD COVER OBTAINED FROM LONG-TERM SOLAR RADIATION MEASUREMENTS IN THE RONDONIA REGION OF BRAZIL

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Abstract

Atmospheric transmission of the incident solar flux, that is the ratio of the solar irradiances measured at the surface and calculated at the top of the atmosphere, was computed at two observational sites in the Rondonia region of Brazil. In order to study the causes of the seasonal variations of the atmospheric transmission, we assessed the water vapor, aerosol and cloudiness effects on the solar radiation attenuation in the atmosphere. For this purpose, the surface solar irradiance and atmospheric transmission was computed at one of the sites for gaseous and gaseous-aerosol cloudless atmospheres employing a broad band radiation code and both aerosol optical depth and precipitable water retrieved from sun photometer measurements. Then, the effect of cloudiness was estimated by calculating the ratio of the surface solar irradiances, measured under cloudy conditions and computed for the clear-sky atmosphere. It was shown that the values of solar radiation attenuation in the atmosphere by water vapor and cloudiness are comparable during the wet season, while the aerosol effect is small. In the dry season, the cloudiness impact on the solar radiation attenuation considerably decreases, while the effect of the smoke aerosols increases.

1. Introduction

Annual cycle of the monthly mean daily average solar irradiance measured in the Rondonia region of Brazil from 1992 to 1993 during the Anglo-Brazilian Amazonian Climate Observation Study (ABRACOS) was reported in [1]. It was shown that the surface solar irradiance S_i changes slightly during a year having two maximums in July and September, but the causes of the seasonal variations of S_i were not studied. We explore them in this research using the larger data set obtained at ABRACOS sites from 1992 to 1995. For this aim, the water vapor, aerosol and cloudiness effects on the solar radiation attenuation in the atmosphere are studied over seasonal time scale. The Rondonia region of Brazil has sub equatorial climate characterized by the strong change of precipitation and cloudiness during a year [1]. Extended thick cloudiness with large cloud amount is observed during the wet season, lasting from December to April, while scattering thin clouds are observed in the dry season, lasting from June to September. The aerosol loading in the atmosphere is small during the wet season due to the strong wet sedimentation of aerosol particles, and it increases in the dry season when savanna and forest fires emit a large amount of smoke aerosols into the troposphere [2].

2. Measurements

The long-term observations of the radiation budget on the ground in the Rondonia region are taken from 1992 at the Reserva Jaru (RJ) forest site (10° 05'S, 61° 55'W) and at the Fazenda Nossa Senhora (NS) pasture site (10° 45'S, 62° 22'W). The detailed description of the ABRACOS sites can be found in [1]. In short, the incident total solar irradiance (300-3000 nm) is measured at 5 minute sampling interval by the CM-5 solarimeter (Kipp and Zonen, Delft, The Netherlands), and its hour average values are recorded by Automatic Weather Station (AWS). The AWS with solarimeter is mounted on the top of a tower at the height 52 m over the ground at the forest site, and it is mounted at the height 5 m over the ground at pasture site.

Fig.1 shows the monthly mean daily average incident solar irradiance, S_i, measured at RJ and NS sites, as well as calculated at the top boundary of the atmosphere S_{top}. The measured data were averaged over four years from 1992 to 1995. S_{top} decreases from January to June due to the change of the astronomical position of Sun, while S_i slightly increases during this period having two maximums in July and September. In order to estimate the solar radiation transmission by the atmosphere, the ratio of the incident solar irradiances at the surface and at the top of the atmosphere, S_i/S_{top}, was calculated. The monthly mean values of S_i/S_{top} shown in Fig.1 increase from 0.4 in January to about 0.6 in July. The strong decrease of S_i/S_{top} in August and September is related to the smoke aerosol impact [3].

The measurements of the direct beam solar radiation by Sun photometers in Brazil's Amazonia were made from 1992 to 1995 at eight selected sites which are part of the global sun photometer network AERONET [2]. The values of the column precipitable water and aerosol optical thickness at eight solar wavelengths 340,380,440,500,670,870,940,1020 nm are retrieved from sun photometer measurements. In the calculations, it was used the longest data set obtained in 1993 at the AERONET site Alta Floresta (AF) (9° 55'S, 56° 00'W) that is from June to December. Fig.2 presents monthly mean values of the aerosol optical depth at 550 nm τ_{550} and precipitable water P_w measured at the Alta Floresta site in 1993. In order to estimate the aerosol optical thickness for period from January to May, when persistent cloudiness prevented sun photometer measurements, it was performed a linear interpolation of τ_{550} data measured in December and June assuming few sources of anthropogenic aerosols during rainy season and strong wet sedimentation of the aerosol particles. The values of P_w for wet season were interpolated taking into account symmetrical seasonal cycle of precipitation in Amazonia [1].

3. Modeled Irradiance

The surface solar irradiance under clear-skies S_i^{clear} was calculated employing a broad band radiation code in which there were adopted available optical parameters of the atmosphere, as well as standard atmospheric models [4]. The aerosol optical thickness at 550 nm and precipitable water, derived from sun photometer measurements, were used as input parameters in this code. Other aerosol parameters were modeled using smoke aerosol model. The detailed description of the aerosol model and radiation transfer code, as well as comparison of modeled and measured irradiances, can be found in [3]. In short, the delta-Eddington technique is used for the radiative transfer calculations in 23 atmospheric layers. The solar spectrum is divided in 14 intervals in visible region and in 3 bands in near infrared one. The k-distribution function [5] is incorporated to compute the water vapor absorption in the near infrared region. The surface albedo adopted for use in the radiation code was measured in the Amazon region [6].

First, the calculations of the surface solar irradiance for the clear-sky atmosphere were performed taking into account solar radiation absorption by ozone and water vapor, and molecular scattering. For this purpose, the ozone amount given by tropical standard atmosphere [4] and precipitable water P_w measured at the Alta Floresta site in 1993 were adopted for use in the radiation code. The results are shown in Fig.3. The gaseous atmosphere attenuates incident solar irradiance by the value that is in the range from 80 W/m^2 to 110 W/m^2, changing slightly its annual cycle. Second, the calculations of the solar radiative fluxes for the gaseous atmosphere with aerosol loading were made. The aerosol optical thicknesses measured at the Alta Floresta site in 1993 were utilized in the calculations. The attenuation of the incident solar irradiance by aerosols was about 15 W/m^2 during wet season, and increased to 60 W/m^2 in August and September during biomass burning period. The difference between the surface solar irradiances, measured under cloudy conditions and calculated for clear-sky atmosphere, is related to the cloudiness impact, which is about 120 W/m^2 in January and only 30 W/m^2 in July.

The atmospheric transmission of the downward solar radiative flux was obtained by calculating the ratio of the incident solar irradiances at the surface and at the top of the gaseous and gaseous-aerosol atmosphere. Fig.4 presents the calculation results for the Nossa Senhora site. The solar radiation absorption by water vapor and ozone changes slightly during a year due to the persistently large amounts of water vapor in the tropical atmosphere. The substantial aerosol impact on the atmospheric transmission is only during biomass burning period in August and September. Fig.4 shows also the ratio of the surface solar irradiances, Si/S_i^{clear}, measured under cloudy conditions and calculated for clear-sky atmosphere. The value of S_i/S_i^{clear} changes from 0.55 in December to 0.85 in July. It is seen that extended thick cloudiness considerably attenuates incident solar radiation at the surface during wet season, while the effect of scattered thin clouds on the solar radiation attenuation in the dry season is small.

4. Conclusions

The long-term measurements of the both aerosol optical depth and surface solar irradiance in the Rondonia region of Brazil made it possible to estimate the water vapor, aerosol and cloudiness effects on the solar radiation attenuation in the tropical atmosphere over seasonal time scale. It was shown that the aerosol impact is substantial during the biomass burning period. The developed approach permitted also to assess quantitavely the cloudiness effect on the surface solar irradiance which is strong during the wet season. The results of the study can be used for the validation of the radiative codes and cloudiness schemes working in general circulation models, as well as for the comparison with satellite observations of cloudiness.

References

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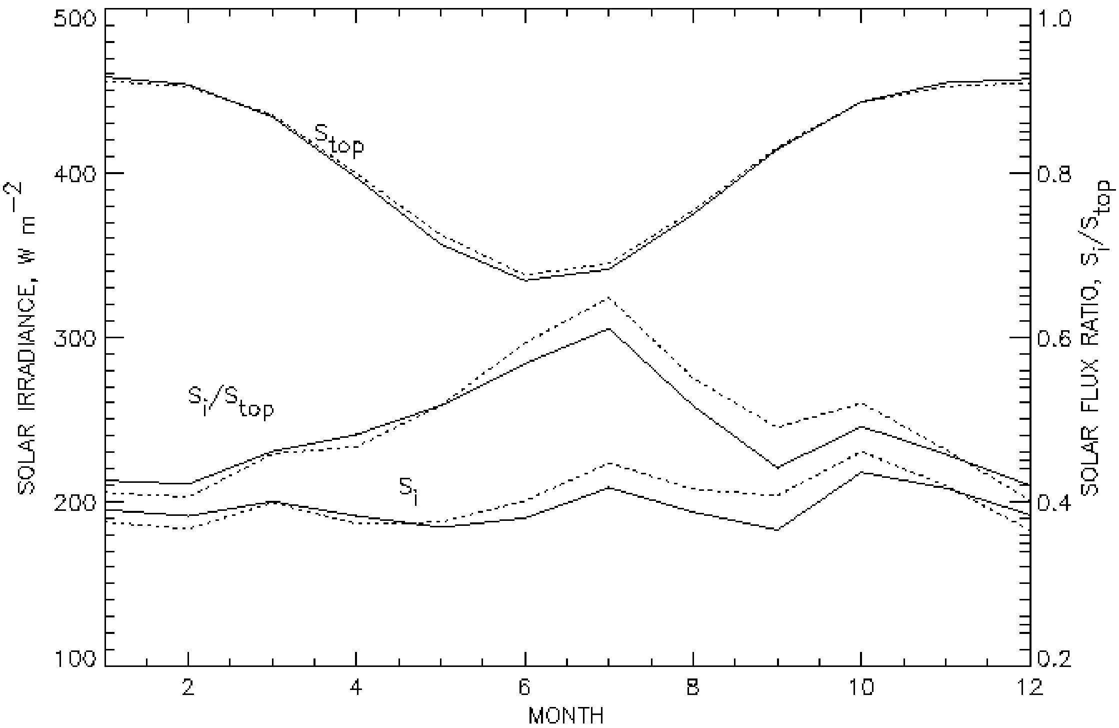

Fig.1: Annual cycle of the incident solar irradiance calculated at the top of the atmosphere (S_{top}) and measured at the surface (S_i) at the Fazenda Nossa Senhora site (solid) and at Reserva Jaru site (dotted) from 1992 to 1995 (four-year means), as well as the atmospheric transmission of the incident solar flux (S_i/S_{top}).

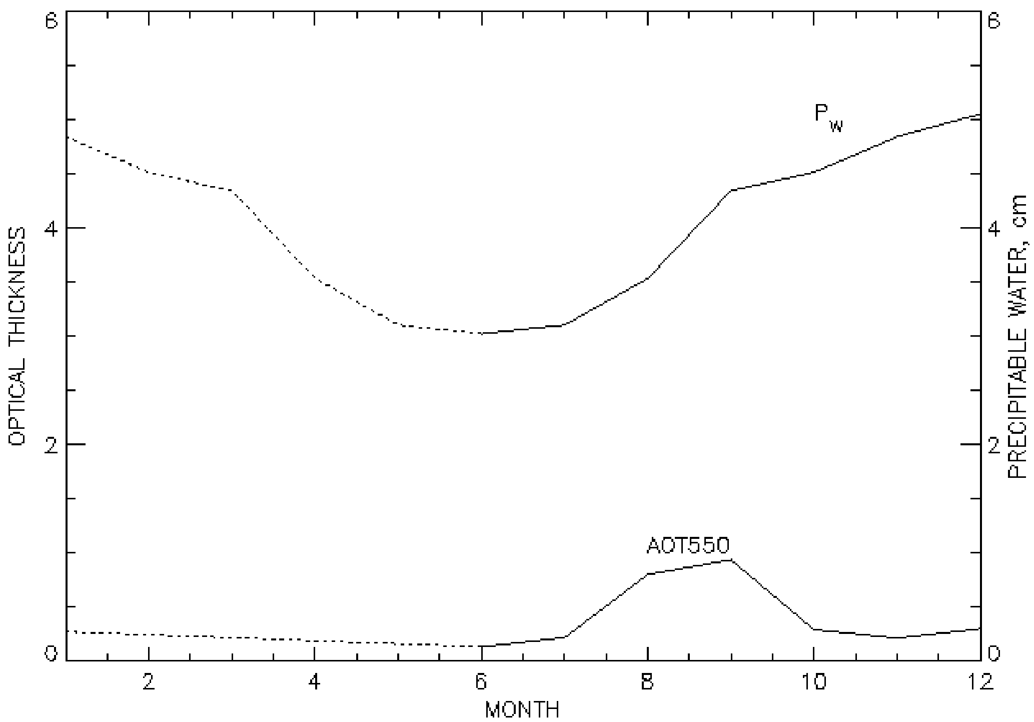

Fig.2: Seasonal variations of the aerosol optical thickness at 550 nm (τ_{550}) and precipitable water (P_w) measured in 1993 at the Alta Floresta site of the global sun photometer network AERONET.

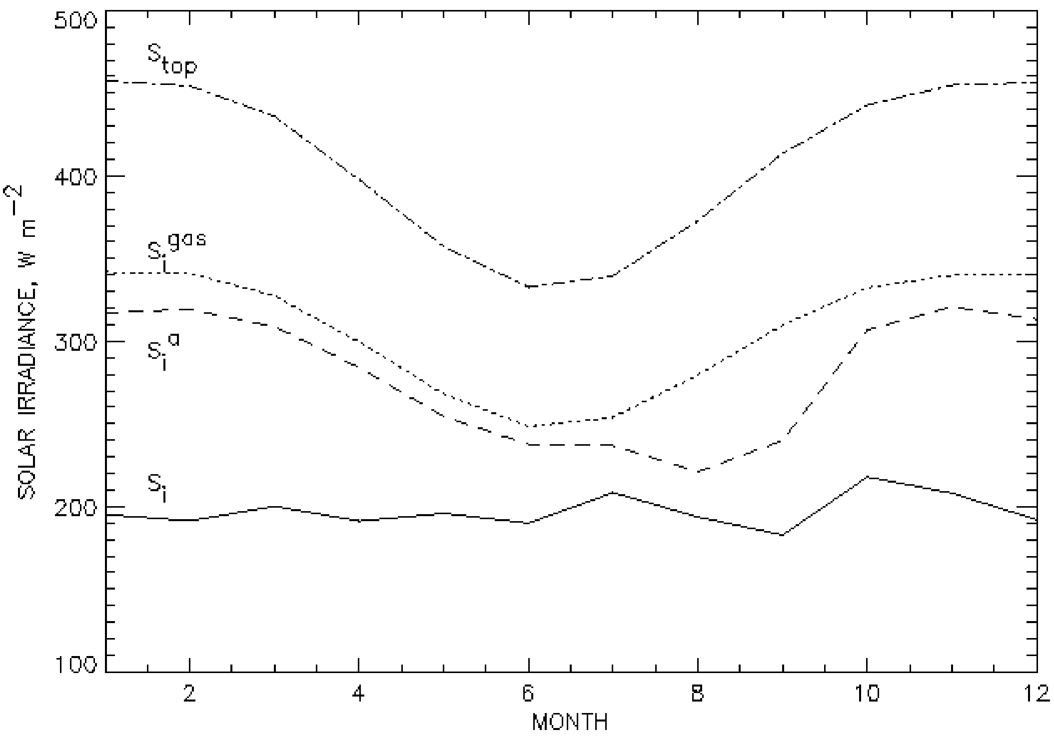

Fig.3: Annual cycle of the incident solar irradiance at the top of the atmosphere (S_{top})and at the surface computed for gaseous atmosphere (S_i^{gas}) and gaseous-aerosol atmosphere (S_i^a), as well as four-year means (1992-1995) of the surface solar irradiance (S_i) measured at the Fazenda Nossa Senhora site.

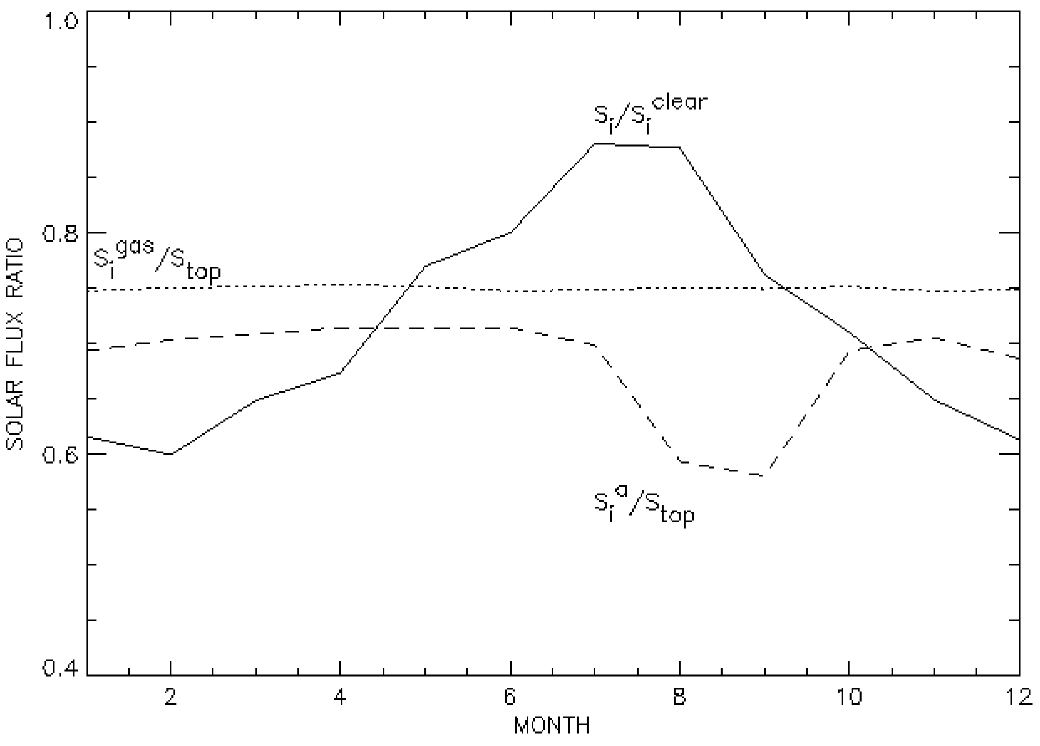

Fig.4: Annual cycle of the atmospheric transmission of the incident solar flux calculated for gaseous atmosphere (S_i^{gas}/S_{top}) and for gaseous-aerosol atmosphere (S_i^a/S_{top}), as well as the ratio of the surface solar irradiances measured under cloud cover and computed for the clear-sky atmosphere (S_i/S_i^{clear}) at the Fazenda Nossa Senhora site.