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Preliminary study of the effect of suspended particulate matter in the atmosphere on solar radiation in Salamanca (Spain)

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Abstract

This paper reports on the preliminary results for Salamanca (Spain) of the relationship between the different components of solar radiation and suspended particulate matter in the atmosphere, characterized as black smoke, during the period from January to September, 1990. Both the total number of days period and clear days only were considered with a view to eliminating the effect of cloud, above all, on the diffuse component of solar radiation. The relationships with diffuse/global and diffuse/direct indices were also studied.

Introduction

Among other parameters, the Earth's climate depends on the chemical composition of the atmosphere as this regulates the radiation balance of the Earth-Atmosphere system. Atmospheric pollution affects this balance of radiation. In addition, atmospheric aerosols absorb and disperse solar and terrestrial radiation.

Several authors have shown that the different components of radiation are disturbed by the emissions from aerosols and by particles arising from industrial activity and traffic, primarily in urban areas (Galindo, 1984).

The aim of this paper was therefore to study the possible effects of atmospheric aerosols on solar radiation in Salamanca.

Experimental

Daily samples were taken in 1990 (from January to September). Suspended particulate matter – characterized as black smoke – was determined by reflectometry and its concentrations expressed in $\mu g\ m^{-3}$. The site where the samples for the meteorological data were taken was the Institute of Natural Resources and Agrobiology of the CSIC in Salamanca, where pollution measurements were also made.

The atmospheric variables in Salamanca (longitude 5° 40′ W; latitude 40° 58′ N) were measured with a UNIDATA model 6003 automatic data collection system provided with model 6504 C sensors for measuring wind velocity, mean temperature and global solar radiation and using model 6505 for measuring diffuse solar radiation following the addition of a model BS-100 shade band. The radiation was measured in units of $W\ m^{-2}$.

Results

The Solar radiation – atmospheric pollution relationship

Initially, a qualitative study was made of the relationship between the daily mean values of global, direct and diffuse radiation and the concentration of black smoke, thereafter, the results which were obtained were checked with regression analysis.

Two series of data were considered:

1) The total number of days studied (series A)
2) Only clear days (series B).

Clear days were considered to be those on which the sum of the three daily observations of cloud ranged from 0 to 4 octas; if this sum lay within 5–19 octas the day was considered to be cloudy and at more than 20 octas it was deemed covered. The aim in this series was to eliminate the effect of cloud on diffuse radiation.

The number of clear days was less than or equal to 5 for each of the months studied with the exception of July and August (17 and 11 days, respectively). According to the climatological study of Roldán

(1987) for Salamanca, the number of clear days in the year studied (1990) was below the annual mean, although the number of hours of sun during the period was greater than the mean.

In order to observe the evolution of direct, diffuse and global solar radiation as the suspended particulate matter in the atmosphere increased, five intervals were set up within series A and series B for the concentrations of black smoke: < 15; 16–25; 26–35; 36–45 and > 45 $\mu g\ m^{-3}$. For each interval the mean value of the three variables were calculated.

It may be seen that from a smoke concentration of > 25 $\mu g\ m^{-3}$ the global and direct components of radiation decrease in proportion to the increase in the concentration of smoke while, by contrast, diffuse radiation increases as the values of such concentrations increase. This is more apparent in the case of the series of clear days (B). These findings are consistent with those of work carried out by other authors at different sites (Karras, 1990).

Solar radiation – atmospheric pollution correlations

In order to quantify the relationships between suspended particulate matter and the radiation variables, simple linear regression analysis was performed with the equation:

$$C_h = a + b\,V_r \qquad (1)$$

where C_h is the concentration of black smoke and V_r is the radiation variable considered.

With respect to the A and B series, for series B, the clear days were separated into polluted and unpolluted days. The distinction between these two types of clear days was established at 25 $\mu g\ m^{-3}$ according to the concentration reached by this pollutant in Salamanca during the sampling time. It should be noted that compared with other more polluted areas, these values are not high, although at the same time, it should be mentioned that the period studied in 1990 was less polluted than the corresponding period in previous years.

Table 1 shows the correlations obtained between black smoke and the different radiation variables, including the D/G and D/I ratios. Many authors consider these to be indices of the amount of aerosols or suspended particulate matter linked to atmospheric turbidity (Aguado, 1990).

For the A series, the radiation variables do not show a significant correlation with black smoke, at least with regard to the mean daily values. However, for the B series, these correlations increase when the effect of cloud is eliminated, above all in diffuse radiation, reaching a correlation coefficient with this variable of 0.65. In the case of the D/G and D/I ratios, the correlations obtained were 0.63 and 0.59, respectively. The correlations that proved to be significant at 99.5%, according to the Snedecor F test, are shown in bold type together with their correlation coefficient. There were no significant correlations to the series of unpolluted clear days.

When considering the series of clear days, the increase in the correlation coefficients of black smoke for all the variables is patent. This is especially the case with diffuse radiation (0.81) and with the D/G ratio (0.82), which in the particular case of Salamanca seems to point to an index of suspended particulate matter in the atmosphere better than the D/I (0.75). The simple regression equations for diffuse radiation (D) and D/G are, respectively:

$$C_{smoke} = 0.53D + 12.94; \quad r = 0.81 \qquad (2)$$

$$C_{smoke} = 98.63D/G + 17.90; \quad r = 0.82 \qquad (3)$$

These equations describe the percentages of variance of the dependent variable of 66 and 68%, respectively. For this same series, the correlation coefficient with direct radiation reached a value of -0.60, pointing to the attenuation of this component with the increase in the concentration of suspended particulate matter in the atmosphere.

Conclusions

From this preliminary study of the relationship between the components of solar radiation and suspended particulate matter in the atmosphere in Salamanca, a clear inverse relationship can be seen between global and direct radiation. In the case of diffuse radiation, the relationship is direct and increases with the increase in the concentration of particles. This is confirmed by the signs of the regression coefficients on quantifying these relationships by regression analysis.

For the study of the diffuse radiation, it is clear that only the clear days should be considered in order to avoid, among other factors, the strong effect of clouds. Global and direct radiation do not show any correlation

Table 1. Coefficients of correlation: black smoke – radiation variables

	Complete	Clear days		
		Total	Polluted	Unpolluted
Global radiation (G)	−0.06	−0.15	−0.38	0.39
Diffuse radiation (D)	0.06	**0.65**	**0.81**	0.45
Direct radiation (I)	−0.07	−0.34	**−0.60**	0.25
D/G	0.03	**0.63**	**0.82**	0.18
D/I	−0.06	**0.59**	**0.75**	0.15

worthy of mention, at least when considering the daily mean values, with the exception of direct radiation on polluted clear days.

It may be seen that, for clear days, apart from diffuse radiation itself, the D/G ratio is a good index (better than D/I) of the concentration of suspended particulate matter in the atmosphere of Salamanca. Although the present study covers the period from January to September 1990, it should be noted that the number of clear days useful for the study decreased, in part, owing to the meteorological peculiarities of that period. This, together with the low concentrations measured with respect to other years, and the fact that we were also working with daily mean values, meant that the correlations were not even higher.

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