

Pinatubo eruption effects on solar radiation at Almeria (36.83° N, 2.41° W)

By F. J. OLMO* and L. ALADOS-ARBOLEDAS, *Grupo de Física de la Atmósfera, Dpto de Física Aplicada, Universidad de Granada, 18071, Granada, Spain*

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ABSTRACT

Volcanic eruptions are responsible for the injection of SO₂ into the stratosphere, and the subsequent production of stratospheric aerosol layer. In June 1991, Mount Pinatubo injected approximately 20 millions metric tons of SO₂ into the stratosphere. The volcanic aerosol circled the earth in 21 days, covering an area of about 42% of the earth's surface. A few weeks after the Mount Pinatubo eruption, an abrupt change was detected on the solar radiation flux measurements registered in our radiometric station, located at a sea shore location (36.83° N, 2.41° W, 10 m a.s.l.). The Mann-Kendall rank statistic confirms this abrupt change with a high confidence level. We have evaluated the quantitative effect over different terms of solar radiation flux. There is a significant reduction in direct solar radiation of about 10%, while global solar irradiance shows a reduction of about 4%, due to the compensation effect of increasing diffuse irradiance. As in similar analyses carried out in mid-latitude locations, we found a decay of the aerosol effects during the 1992 summer and an enhancement in late 1992.

1. Introduction

In June 1991, the eruption of Pinatubo in the Philippines released about 20 million tons of sulphur gas into the lower stratosphere up to an altitude of 30 km (Bluth et al., 1992). The analyses of McCormick and Veiga (1992), show that the aerosol particles were concentrated between 16 and 25 km above sea level. Stowe et al. (1992) have monitored the Pinatubo aerosol layer with NOAA/11 AVHRR data. They have shown that volcanic aerosols circled the earth in 21 days, and that 9 weeks after the eruption, the volcanic aerosol layer covered the latitude zone 30° N to 30° S, with patches at higher latitudes. Blumthaler and Ambach (1994) have detected a reduction of about 10% in direct solar irradiance, for solar elevations between 30° and 60°, in a Swiss high-Alpine station, due to the Mt. Pinatubo volcanic aerosols. They compare 10 min of data registered in May–June 1991 and May–June 1992. In a

similar study, Michalsky et al. (1994) detected the effect of the Mount Pinatubo eruption, in various mid latitude locations. They found a reduction on hourly direct solar radiation of about 15–20% during the 1992 winter, using data within 1, 2 or 3 h of local noon.

In this work, we study the effects of Mount Pinatubo in a mid-latitude coastal location. Our approach is to use the data base of global horizontal and direct normal irradiances registered in the seashore radiometric station of the University of Almeria, that includes measurements before and after the eruption in June 1991.

2. Data and measurements

The radiometric data used in this study have been measured in the radiometric station of the University of Almería, a seashore location (36.83° N, 2.41° W). Broadband horizontal solar irradiance (0.3–3 µm), global and diffuse, photo-synthetically active radiation (400–700 nm), and

* Corresponding author.

long-wave atmospheric irradiance ($4\text{--}100\ \mu\text{m}$), have been continuously registered since the beginning of 1990. Kipp & Zonen pyranometers, model CM-11, were used for measuring the solar irradiance, while the photosynthetically active radiation and the long-wave atmospheric irradiance were measured by means of LICOR-190-SZ and Eppley-PIR, respectively. The measurements are registered at 1-min intervals and stored at 10-min averages. The pyranometers are intercompared yearly against a reference CM-11, reserved for this purpose, and exposed to solar radiation only during these intercomparison campaigns. Air temperature and relative humidity at 2 levels are also included among our continuous registers. From this data base, hourly values, covering the period from June 1990 to December 1992, were generated for the present study. Cloud-cover data registered in Almería Airport, located ca. 1 km away from the radiometric station, at 30-min intervals have been added to the data base.

The diffuse irradiance, measured by shadow-band, has been corrected using the model developed by Batlles et al. (1994). These corrected data and the global irradiance measurements have been used to evaluate the solar direct irradiance hourly values.

Our radiometric station is located in the Mediterranean coast in Southeastern Spain and is characterized by great frequency of cloudless days, and the persistence of a high-humidity regime.

3. Analysis and results

To analyse the Mt. Pinatubo aerosols effect, only data recorded in cloudless conditions were used for the study; for this purpose, we have used the cloud observations registered in the Meteorological Office of Almería Airport. Another limitation imposed on the analysis is the use of data taken within 2 h of local noon.

Fig. 1a represents the hourly direct solar irradiance time series plot for cloudless days, including data taken within 2 h of local noon. There is a clear decreasing tendency, while a similar analysis shows an inverse tendency in the diffuse irradiance.

To check statistically the existence of an abrupt change, we applied the sequential version in time of the Mann-Kendall rank statistic proposed by

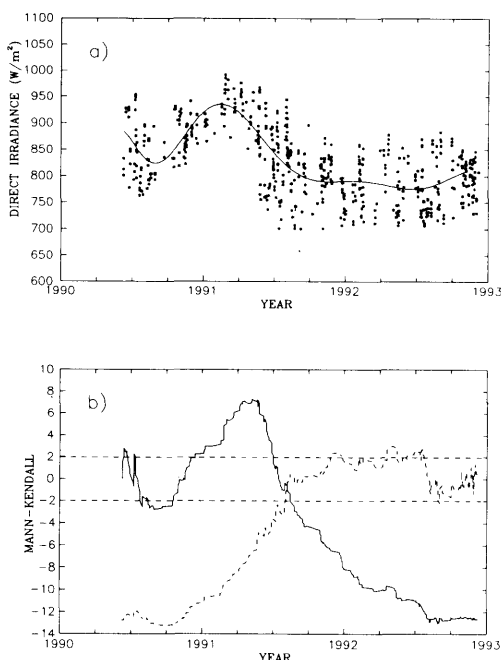


Fig. 1. (a) A time series plot of direct solar radiation hourly values for clear days within 2 h of local noon. The solid line represents the trend of monthly average hourly values for data within 2 h of local noon. (b) Direct solar radiation sequential onward (full line) and backward (dashed line) trend tests. The dotted lines indicate the standardized values of the Mann-Kendall test, that correspond to the 5% significance level.

Sneyers (Sneyers, 1992). This test allows the detection of the approximate beginning of a change through a graphical technique which uses the onward and backward trend analyses of the Mann-Kendall statistic. If an intersection between the two resulting lines exists in the region of ± 1.96 of the standardized statistic, corresponding to the 5% significance level, we can consider the existence of an abrupt change in our temporal series. Fig. 1b represents the results of the Mann-Kendall test applied to the direct solar irradiance series. We found a clear intersection of the sequential onward (full line) and backward (dashed line) during August 1991. As the values of the standardized statistic are close to zero in the intersection point, this result has a high confidence level, and can thus be considered as evidence of a sharp change in this temporal series. This finding is in accordance with the arrival of the volcanic aerosol to our latitudes

(Stowe et al., 1992). The magnitude of this change has been evaluated for the previous and subsequent weeks to the sharp change detected by the Mann-Kendall test. We found a reduction of about 10%. Our analyses also showed that during winter 1992, there is a reduction of about 10% with respect to winter 1991 (pre-eruption conditions), while summer 1992 presents solar direct irradiance values 6% lower than those encountered in summer 1991 (pre-eruption conditions).

We have also performed this test over the solar diffuse and global series. A similar level of significance has been obtained for the solar diffuse series. On the other hand, application of the Mann-Kendall test to the global solar horizontal irradiance supports the hypothesis of a change following the Pinatubo aerosol layer extension to our latitudes, Fig. 2. Nevertheless, the magnitude of the solar global irradiance reduction presents a value close to 4%, obtained by comparing the weeks before and after the evidence of change. On the other hand, the study of differences between

monthly average hourly values, for months before and after the volcano eruption (i.e., February 1991 and February 1992, and so on), shows an erratic behaviour around zero, which does not support the existence of an abrupt change in solar global irradiance. In this sense, it is interesting to note that although the Mann-Kendall sequential test shows intersections both for direct solar irradiance and solar global irradiance, the behaviours of the onward and backward trends for these variables are very different (see Figs. 1 and 2).

To isolate the influence of the aerosol, we have evaluated the transmittance due to aerosols, T_a , using single-parametric models. We have used the Gueymard and Iqbal C models (Gueymard, 1993), obtaining similar results in both cases. In this way, we have excluded the water-vapour effect, evaluated by means of relative humidity and temperature measured at screen level. For the contribution due to gases, we have used climatological values. The Mann-Kendall test suggests a sharp change towards higher values in the aerosols' optical depth, τ_a , evaluated from the aerosols transmittance values, T_a , Fig. 3.

As shown in Figs. 1 and 3, after the sharp change suggested by the Mann-Kendall test, the volcanic aerosol extinction process increased during autumn 1991 and winter 1992. At this time, it reached its maximum value, with an hourly direct solar radiation reduction of about 15%, for values within 2 h of local noon. In this sense, during summer 1992, a decay of the volcanic aerosol extinction is shown, reaching the direct radiation reduction values close to 6%. Nevertheless, at the end of 1992, there is a recovery of the extinction process, with a reduction of direct solar radiation of ca. 9% with reference to pre-eruption autumn values. This result is similar to that detected by Michalsky et al. (1994) in their analysis of Mt. Pinatubo eruption effects, where they found a similar decay of volcanic aerosol effects, interrupted by the presence of a recovery at the end of 1992. Previous analyses of the effects of the El Chichon eruption (Michalsky et al., 1990) have revealed a similar pattern, with winter extinction recovery. This fact has been justified by the possible winter transport from a tropical reservoir, which is slowly decreasing (Michalsky et al., 1990).

As to the results of similar studies, in their analysis of the high-alpine station of Jungfraujoch, Blumthaler and Ambach (1994) found a significant

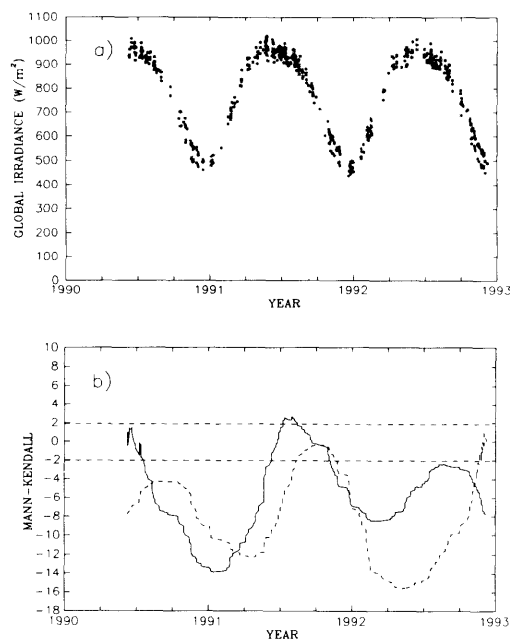


Fig. 2. (a) Time series plot of hourly global horizontal irradiance for clear days within 2 h of local noon. (b) Global horizontal irradiance sequential onward (full line) and backward (dashed line) trend tests. The dotted lines indicate the standardized values of the Mann-Kendall test that correspond to the 5% significance level.

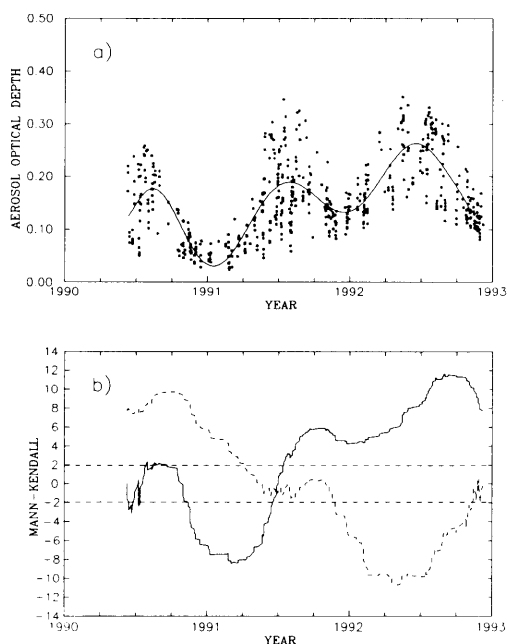


Fig. 3. (a) Time series plot of aerosols optical depth hourly values within 2 h of local noon. (b) Aerosols optical depth sequential onward (full line) and backward (dashed line) trend tests. The dotted lines indicate the standardized values of the Mann-Kendall test that correspond to the 5% significance level.

reduction of direct solar radiation of about 10%, comparing 2 data sets: one obtained in 1991, several weeks before the eruption, and the other during the same period of 1992. In their analyses of various mid-latitude stations, Michalsky et al. (1994) have found an increasing reduction in direct solar radiation by late summer 1991, with peak extinction during the winter 1992 of 15 to 20%. During summer 1992, they found a substantial recovery of direct solar radiation. In this sense, our results present greater accordance with the pattern shown in the Michalsky et al. (1994) study. Michalsky et al. (1994) suggest that assuming Pinatubo aerosol follows the same pattern as the el Chichon aerosol, the extinction process must reach values close to 10–13% during winter 1993. Our results confirm that at the end of 1992, there is an increase in direct solar radiation extinction, that supports this hypothesis. Nevertheless, the analysis of the 1993 and 1994 data will provide the final contrast for this winter extinction increase. The direct solar radiation reduction values

encountered in our station during winter 1992 are similar to those encountered by Michalsky et al. (1994) in their analysis. On the other hand, the reduction encountered during summer 1992 compared to summer 1991 in the study of Blumthaler and Ambach (1994) is clearly greater than shown by our results for the same period. Our summer results are closer to those of Michalsky et al. (1994), involving a station with altitudes substantially lower than that of Jungfraujoch, in the Swiss Alps.

4. Summary

The application of the Mann-Kendall sequential test, over the radiation fluxes time series registered in our radiometric station, suggests the existence of a sharp change in solar radiation, direct and diffuse components, coinciding with the arrival of the Pinatubo aerosol cloud in our latitudes. The direct irradiance values at a sea-level location, in Southeastern Spain, present a reduction of about 10% a few weeks after the Pinatubo eruption. Diffuse irradiance presents an increase of about 43%, with a minor effect on global irradiance, which shows a reduction of about 4%. The effects of the aerosol cloud are evident during 1992, reaching their maximum extinction levels during winter and decaying substantially in summer. Nevertheless, there is a recovering of the extinction process at the end of 1992.

We have found similar direct radiation extinction effects to those reported by Michalsky et al. (1994) for various mid-latitude stations, but with some differences compared to those obtained by Blumthaler and Ambach (1994) for a high-Alpine station in Switzerland.

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