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Ground-based observations of solar radiation at three Italian sites, during the eclipse of 29 March, 2006: Signs of the environment impact on incoming global irradiance

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ABSTRACT

The time-patterns of ground-level solar irradiance during the solar eclipse of 29 March, 2006, were observed at three Italian stations (Lampedusa, Mt. Cimone and Bologna) using different radiometric techniques. The global irradiance measured at the sites was found to reach the minimum at times not coinciding with those predicted by radiative transfer model evaluations, with ahead or lag times depending on the optical characteristics of the surface–atmosphere system in the areas surrounding of the stations. This different behaviour has been mainly attributed to the different influence of the environmental conditions on the diffuse radiance component measured at the observation sites. The present results indicate that the incoming diffuse radiance recorded at the three stations was appreciably affected by contributions arising from extended regions of about 30–100 km range from the stations. Such an explanation agrees very well with the theoretical evaluations obtained in earlier studies. The surrounding environmental areas of impact at ultraviolet wavelengths have been found to be wider than those in the visible and near-infrared spectral ranges.

1. Introduction

Solar eclipse episodes are often favourable opportunities for closely observing the effects of interactions between solar irradiance and the terrestrial atmosphere (Abbott, 1958; Carapiperis and Karapiperis, 1959; Pruitt et al., 1965; Anderson et al., 1972; Zerefos et al., 2000; Koepke et al., 2001; Dani and Devara, 2002; Blumthaler et al., 2006). Studies on this topic can be very useful for testing and improving the radiative transfer models used to simulate the spectrum of ultraviolet (UV) solar irradiance reaching the surface (Emde and Mayer, 2007). Investigations performed so far have shown that the ground-level solar irradiance during a period of solar disk obscuration by the Moon begins to decrease at approximately the first eclipse contact time, reaches the minimum in correspondence of the eclipse's maximum, and then increases again until the fourth contact time. However, some studies have highlighted appreciable deviations from the average irradiance time-patterns

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measured during previous eclipse episodes. For instance, measuring the solar direct broadband irradiance during the eclipse of 25 February, 1952, in Greece, Abbott (1958) found that the irradiance started to diminish 12 min before the first contact time and, subsequently, continued to assume lower values than usual throughout a certain period after the last contact. A similar irradiance drop prior to the first contact can be noticed on examining the data reported by Miyake et al. (1949). However, Carapiperis and Karapiperis (1959) did not observe such occurrences, when they performed solar irradiance measurements in Greece, during the eclipse of 30 June, 1954.

Pruitt et al. (1965) carried out solar irradiance measurements at Davis (USA) during the eclipse of 20 July, 1963, recording a decrease in solar irradiance reaching the surface about 5–6 min before the first contact time, and the diffuse radiation minimum a only few minutes before the maximum obscuration of the solar disk. Both Zerefos et al. (2000) and Blumthaler et al. (2006) measured the lag of the diffuse irradiance minimum with respect to the eclipse maximum time, explaining the phenomenon as plausibly due to the appreciable contribution of diffuse radiance from areas far from the station and more weakly shadowed by the Moon. As a result, solar irradiance did not closely follow the normal eclipse evolutionary patterns in such cases, where the discrepancies were generally attributed to the variable effects of the eclipse on the solar diffuse radiance field, whose features depend closely on the atmospheric environmental conditions. In fact, the global solar irradiance reaching the Earth's surface consists of both direct and diffuse radiation components. The former depends only on the parameters characterising the optical properties of the atmospheric slant path described by the incoming solar rays, while the latter arises mainly from the scattering processes due to air molecules (Rayleigh scattering) and aerosols (Mie scattering), taking place over a large area around the measurement site (Iqbal, 1983).

In addition, the solar radiation partly reflected upward by the surface or by clouds can be scattered by air molecules and aerosols, sometimes enhancing considerably the incoming diffuse radiance flux measured at the observation site. Since Rayleigh scattering closely depends on wavelength, the diffuse radiance is comparable to, or may become even more intense than the direct component at UV wavelengths, with significantly lower values at the longer wavelengths in the visible and near-infrared spectral ranges. Depending strongly on the atmospheric turbidity conditions and surface reflectivity characteristics, UV diffuse radiance can vary greatly as a function of the environmental parameters. These dependence features have been the subject of numerous studies.

Huber et al. (2004) investigated the influence of non homogeneous surface albedo on the diffuse radiation, finding that large heterogeneities can characterise the distribution of the UV component over a not uniform observation area, with discrepancies of up to 40% between the radiation fields measured over a snow-free terrain and a snow-covered surface. Kylling and Mayer (2001) compared field measurements of UV irradiance over an area containing high, snow-covered mountains and ice-free water surfaces with 3-D model simulations. Considering various snow-cover characteristics, they gave evidence of a radiation enhancement of about 23–27% for clear-sky conditions and 40–60% in overcast cases, due to the high reflectance features of the snow surface. Similar results were obtained by McKenzie et al. (1998) over some snow-covered areas, showing an increase in the global solar irradiance, equal to 22% and 28% in the UV-A and UV-B bands, respectively. In Antarctica, Smolskaia et al. (1999) measured an increase in the UV global irradiance of about 10% over snow surfaces, with respect to analogous measurements taken over open sea-water surfaces. The results were subsequently confirmed by Mayer and Degünther (2000) using model simulations.

Also employing model evaluations, Lenoble (2000) studied the impact of surface reflectance characterising the surrounding area on the zenith radiance reaching the ground for cloudless sky conditions. She found that (i) approximately 12–15% of the reflected photons came from the region within 1 km around the observation site, (ii) about 25–30% from the surrounding area within the 1–5 km radius range, (iii) 43–47% from the 5–30 km radius range, and (iv) 10–15% due to multiple reflections from more distant areas.

With regard to cloud effects, Degünther and Meerkötter (2000) studied the impact of remote clouds on ground-level solar UV radiation, by analysing the different spatial distribution of cloud layers around the observation site. Using a three-dimensional radiative transfer model, they found that clouds about 15–20 km from the site can strengthen the incoming UV radiation at the surface by 15% and more, or reduce it by more than 50%, while more distant clouds were estimated to exert a less marked influence, contributing to the ground-level UV irradiance by a few percent only.

Thus, the environmental characteristics around an observation site are expected to impact significantly on the solar radiation density flux measured at the ground, especially on its UV spectral component. However, while the influence of factors located in proximity of an observation site has been investigated with both theoretical simulations and experimental methods, the influence of diffuse radiation originating from distant regions has generally been analysed and estimated by means of physical models only, without using experimental data. Given the scales of the Moon penumbra, where the distances between sites presenting appreciable discrepancies of the shadow intensity reach 100 km or more, it is evident that solar eclipse events can present favourable conditions for monitoring the effects produced by remote environmental factors on ground-level solar radiation. When the Moon's umbra moves on the Earth surface, it shadows consecutively the diverse parts of the areas around the measurement station, to various extents. By associating such occurrences with the surface radiance time-patterns, the present study attempts to evaluate the extension of the area around the station that contributes to cause a significant impact on the solar radiance field measured at the ground.

2. Instruments used at the three Italian sites and description of local eclipse circumstances and meteorological conditions

The incoming solar irradiance was measured within different spectral bands at three Italian sites, with latitudes ranging from 35 °N to 45 °N, during the eclipse of 29 March,