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Analysis of solar irradiation measurements at Beer Sheva, Israel from 1985 through 2013

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ABSTRACT

An in-depth analysis of the solar horizontal global, normal incidence beam and solar global incident on a south-facing surface tilted at 40° irradiation monitored at Beer Sheva from 1985 through 2013 has been performed. The horizontal beam irradiation, daily clearness index, daily beam index and beam fraction of the horizontal global irradiation were determined from the measured parameters. A statistical analysis, which included average, median, standard deviation, maximum and minimum values and the coefficient of variation, was performed on the parameters under investigation. The monthly frequency distribution types were determined for the solar global, normal incidence beam and solar global incident on a south-facing surface tilted at 40° irradiation based upon their corresponding skewness and kurtosis values. In addition, typical meteorological years were developed for the solar horizontal global and normal incidence beam irradiation.

Beer Sheva is characterized as a site with a high incidence of clear days with global irradiation consisting of a relatively high beam fraction. A relatively steep minimum in the annual average daily normal incidence beam irradiation is observed from 1991 to 1993 and has been attributed to the eruption of Mt. Pinatubo, Philippines during June 1991. A time series analysis of the both individual monthly and annual average daily global and normal incidence irradiation indicated a slight trend of solar brightening for this region during the time interval 1985 through 2013, but in most cases they were not statistically significant based upon their p values.

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1. Introduction

There have been a number of reports describing the reduction in the terrestrial intensity of the solar irradiation, which has been attributed to increased aerosols caused by anthropogenic pollution, in many regions of the earth. This process is often referred to as 'solar/global dimming' (Stanhill and Kalma [1], Stanhill and Cohen [2,3]. The terrestrial solar irradiation intensity is also a function of the degree of cloud cover. It should be noted that it is not sufficient to take into account just cloud cover and aerosol loading but also the type and height distribution of the clouds and size and composition of the aerosols.

Stanhill and Kalma [1] observed that over a 35 year interval (ca. 1960–1994) the solar irradiation intensity in Hong Kong decreased by more than one-third. During this time interval the population doubled and the total use of fossil fuels increased by more than a factor of seven. The observed decrease in solar irradiation intensity can be attributed to a significant extent to anthropogenic pollution. Stanhill and Moreshet [4] analyzed irradiation measurements made between 1958 and 1985 at about 200 stations of the World Radiation Network and found a weighted mean reduction of 9 Wm^{-2} (5.3%) during this time interval for the land surfaces studied. The greatest reduction was observed for in the mid-latitudes of the Northern Hemisphere, approaching that of Hong Kong or that measured between 1956 and 1987 at Bet Dagan, Israel (a site downwind of the Tel Aviv-Yafo metropolis), cf., Stanhill and Moreshet [5]. They attributed the decrease to be mainly a result of anthropogenic pollution, as in the case of Hong Kong. Stanhill and Cohen [2] reviewed accurate measurements made with thermopile pyranometers during the previous 50 years and concluded that the reduction in solar irradiation globally averaged 0.51 ± 0.05 Wm^{-2} per year, which is equivalent to a reduction of 2.7% per decade and totals 20 Wm^{-2}, seven times the measurement error. Grimenes and Thue-Hansen [6] arrived at almost the identical conclusion utilizing data measured at the Norwegian University of Life Sciences (located in a rural area 35 km south of Oslo). Their analysis showed a reduction of 2.5% per decade based upon a reliable set of data consisting of 31 years of measurements (recorded between 1950 and 2003).

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Liepert [7] analyzed terrestrial solar irradiation at sites in the United States and worldwide from 1961 to 1990. She found that the solar irradiation intensity declined approximately by 7 Wm^{-2} or 4% during this time interval worldwide. She also observed that the greatest declines, ca., 19 Wm^{-2} or 10%, occurred in the United States sites and attributed these declines to clear sky and cloud optical thickness, i.e., aerosol loading and cloud cover.

Perrson [8], on the other hand, reported an increasing trend in the terrestrial solar irradiation measured by 12 Swedish meteorological stations during the years 1983–1997. The increasing trend in terrestrial solar irradiation averaged over the 12 stations was found to be 7.2% per decade. He attributed this to decreasing cloud cover, especially during the summer months.

Biggs et al. [9] studied the decadal trends in cloudiness and their affect on the terrestrial solar irradiation in the Krishna River basin in southern India, from 1952 to 1997. They observed that the average annual cloudiness observed at 14 meteorological stations scattered across the basin decreased by 0.09% per year over this time interval. The reduced cloud cover compensated for the negative effect of aerosols on the terrestrial solar irradiation and a small increase in solar irradiation was observed during the monsoon months (0.1–2.9 Wm^{-2} per decade). During the non-monsoon months the aerosol loading dominated over the cloud cover and resulted in a decrease in terrestrial solar irradiation (2.8–5.5 Wm^{-2} per decade).

Stanhill and Cohen [3] utilizing terrestrial solar irradiation measurements in Israel between 1954 and 2007 observed a significant temporal variation during the last half century: viz., solar dimming during the third quarter of the past century and partial recovery/brightening in the last quarter. They studied data from three different regions in Israel having very diverse population densities, both in overall trends and rate of change during the periods of dimming and brightening. They observed that in all regions studied the overall trend in terrestrial solar irradiation was negative, i.e., dimming, and was related to the logarithm of the mean population density. The rates of change during the dimming and brightening periods were found to be unrelated to the rate of population change. In addition, trends in maximum, minimum, mean and diurnal ambient temperatures were significant and differed between regions but were not clearly related to either terrestrial solar irradiation or population density trends.

Muller et al. [10] studied long-term trends of solar irradiation at a number of sites in Germany between 1951 and 2010. They observed a dimming trend from the beginning of the data set, 1951, trough 1983, whereas a brightening trend was observed from 1984 to the end of the period under investigation, viz., 2010. The calculated trend for all stations analyzed for the dimming period is (−1.7 ± 1.3) %/decade, whereas that for the brightening period is (3.3 ± 1.6)%/decade.

The present analysis is based upon measurements performed at the Ben-Gurion University of the Negev's meteorological station. It has been monitoring solar irradiation since 1976 but its location was changed in the early 1980's and the present analysis utilizes a database consisting of only those measurements recorded at its present site. This long-term database has been analyzed on a monthly and yearly basis to determine if there are any statistically significant trends in the monthly and annual average daily values of the terrestrial solar irradiation parameters measured during this time interval.

2. Measurements

The present analysis utilizes measurements recorded by the Solar Energy Laboratory's meteorological station during the time interval October 1985 through August 2013. The meteorological station is located in Beer Sheva on the main campus of the Ben-Gurion University of the Negev (31°15′N, 34°45′E, 315 m m.s.l.), i.e., on the roof of the Poster Building. Beer Sheva is situated at the northern edge of the semi-arid Negev region of Israel. The global irradiation, on both a horizontal surface and a surface tilted at 40° to the south, is measured using Eppley Precision Spectral Pyranometers, Model PSP. The normal incidence beam irradiation is measured using an Eppley Normal Incidence Pyrheliometer, Model NIP. This station is part of the national network of meteorological stations and the Israel Meteorological Service checks the instruments' calibration constants at regular intervals. A Campbell Scientific Instruments data-logger, Model CR10, monitors and stores the data at 10-min intervals (i.e., the meters are scanned at 10 s intervals and average values at 10 min intervals are calculated and stored). The data are transmitted periodically from the data-logger to the Solar Energy Laboratory via modem.

3. Data analysis

The measured hourly values of the horizontal global and normal incidence solar irradiation were subjected to the quality control filters as specified by the Commission Internationale de l'Eclairage (CIE), cf., de Miguel et al. [11]:

Horizontal solar global irradiation

$$0 \leqslant I_{g,h} \leqslant 1.2 I_{0,h} \tag{1}$$

Normal incidence solar beam irradiation

$$0 \leqslant I_{b,h} \leqslant I_{0,h} \tag{2}$$

where $I_{g,h}$ the hourly horizontal solar global irradiation, $I_{0,h}$ the hourly extraterrestrial horizontal solar irradiation and $I_{b,h}$ the hourly horizontal solar beam irradiation. The hourly horizontal solar beam was determined from the measured normal incidence solar beam irradiation, $I_{b,n}$, using the relatively simple geometrical relationship between the surfaces involved, viz.,

$$I_{b,h} = I_{b,n} \cos \theta_z \tag{3}$$

where θ_z is the zenith angle.

The hourly solar diffuse irradiation on a horizontal surface, $I_{d,h}$, was determined from the difference between the corresponding horizontal solar global and beam irradiation values, i.e.,

$$I_{d,h} = I_{g,h} - I_{b,h}. \tag{4}$$

The monthly average daily clearness index K_T and daily horizontal beam index K_B, defined as

$$K_T = \left(\sum H_g/H_0\right)/n \tag{5}$$

$$\text{and} \quad K_B = \left(\sum H_{b,h}/H_0\right)/n, \tag{6}$$

where H_g, $H_{b,h}$, H_0 are the daily global, horizontal beam and horizontal extraterrestrial solar irradiation and n the number of days, were also calculated.

Two different methods were utilized in the data analysis to determine the monthly average daily values.

- The database was arranged on a monthly basis, irrespective of year of measurement. All available (after application of the quality control filters) hourly values for a single month were utilized in order to determine the monthly average hourly values. These average hourly values were then summed to determine the monthly average daily values.
- The databases utilized in the above were subjected to a secondary filter that eliminated all days for which a complete set of data did not exist, i.e., missing an hourly value. The monthly

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