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Estimation of Turbidity and Global Radiation over Jeddah in Spring

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ABSTRACT. An experiment was performed for estimation of turbidity over Jeddah during Spring (March, April and May 1993).

The measurements include direct, diffuse and global radiation, on clear days. The data are also incorporated in a radiation model for estimation of different components of solar radiation over Jeddah. The results showed that the turbidity and consequently the amount of aerosols in the atmosphere was maximum in April. This was accompanied by a strong south to southwest wind. The coefficient of turbidity (β) reached (0.9) on 6 April, a very turbid day. On this day, the wave length exponent (α) approached zero. The diurnal variation of the turbidity showed an increase started at noon and extended all afternoon. The average Spring turbidity in Jeddah is (0.18). The results of the model indicate that the average percentage difference between the measured and the calculated direct, diffuse and global radiation are 8%, 15% and 5% respectively. The model used was successful, with an over all precision for direct and global radiation of 10% for Jeddah. This gives confidence that this model probably with some improvements, can be used for estimating global radiation over Jeddah on clear days when measurements of this parameters are not available.

Introduction

Radiation does not pass unimpeded through the atmosphere; part is reflected back to space, part is scattered or absorbed by the atmosphere and part reaches the ground. Both the scattering and absorption of radiation in the atmosphere depend directly upon the properties of the gas molecules and any natural or man made particulates present (Anthes *et al.* 1975). Atmospheric molecules are much smaller than the wavelengths of visible light. Therefore, the shorter wavelengths are scattered more than the longer ones (Liou 1980). The Radiation Budget helps us understand what happens to the radiation beam in the atmosphere. About 30% of the incident solar radiation is scattered or reflect back to space, 20% is absorbed directly by the clouds and atmosphere and 50% is absorbed by the earth's surface (Trewartha and Horn 1971, Battan 1982, Peixoto and Oort 1992). In this study the turbidity parameters were calculated for Jeddah in Spring. Jeddah is a coastal city located on the red sea and surrounded by mountains on the NE, E and SE. This topography may influence the turbidity over the city. Also, Jeddah has seen, during the last decade, rapid growth of industrial activities which add aerosols to the atmosphere above. The solar radiation measurements provide indication of aerosol level over the city. This in turn improves our understanding about the attenuation of solar radiation due to atmospheric aerosols.

Different methods are used for estimation of the aerosols in the atmosphere. This is done by calculation of a turbidity coefficient (β). The methods use Angstrom turbidity formula (Angstrom, 1929, 1930).

One of the methods uses measurements at wave length of one micron in order to determine the coefficient of attenuation of solar beam due to scattering and absorption of aerosols (Iqbal, 1983). This assumes no absorption is taken place by mixed gases and ozone, as well the water vapor has a weak absorption at this wave length. Thus the attenuation results mainly from aerosols and to a less extent by water vapor and Rayleigh scattering.

Another method (IGY Instruction Manual, 1958) assumes fixed size distribution of aerosol particles ($\alpha = 1.3$) while the measurements are performed at any specific wave length (λ), at which one or more of the absorption coefficients due to water vapor, mixed gases and ozone can be neglected.

A third method (Iqbal, 1983) uses the Angstrom formula at two wave lengths, usually taken as 0.38 μm and 0.5 μm. At the first wave length there is no molecular gas absorption and at the second wave length ozone has weak absorption.

The fourth method uses transmittances due to Rayleigh scattering, ozone, aerosols, mixed gases and water vapor. The total atmospheric transmittance is estimated from direct solar radiation measurements at the surface and at the top of the atmosphere. Thus, the aerosol transmittance is deduced from a combined formula of the above mentioned transmittances (Iqbal, 1983). In this case, the measurements are taken at any two wave lengths and using Angstrom turbidity formula, the Angstrom turbidity coefficient (β) and wave length exponent (α) can be deduced.

To estimate the global, diffuse and direct radiation, a model developed by a number of authors (Davies *et al.*, 1975, Suckling and Hay, 1976, Davies, 1980) was used.

2. Estimation of Angstrom Turbidity Coefficient (β) and Wave Length Exponent (α)

The method used in this study is that applicable for the sun photometer (Mainz sun photometer, Model Ms II-85-45) designed by Dr. G.A. d'Almeida, institute of meteorology, Munch university. The formula of the aerosol optical thickness per unit optical mass of the air ($T_a(\lambda)$) is given by :

$$T_{a\lambda} = (1/M)\ ln\ (I_{o\lambda} / I_{\lambda} * s) - [P/P_o\ T_{r\lambda} + T_{o\lambda}] \quad (1)$$

Where

$I_{o\lambda}$ is the extra terrestrial radiation at mean sun-earth distance.

I_{λ} is the radiation at the observing point. This is measured by the sunphotometer.

s is the correction factor for mean sun-earth distance.

M is the relative optical air mass, a function of the solar elevation angle.

To calculate M, the following formula is used :

$$M = 1 / [\sin h + 0.15 \, (h + 3.885)^{-1.253}] \tag{2}$$

where (h) is the elevation angle in degree.

P, P_o are station pressure and standard pressure at mean sea level.

(P_o = 1013.2 hpa)

$T_{r\lambda}$ is the Rayleigh scattering optical thickness or scattering due to air molecules, normalized to P_o. It is calculated from the following formula :

$$T_{r\lambda} = 0.00838 \, \lambda^{-(3.916 + 0.0742\lambda + 0.05/\lambda)} \tag{3}$$

where λ is the wavelength in μm.

$T_{o\lambda}$ is the optical thickness for ozone. It is given by the following formula :

$$T_{o\lambda} = k_{o\lambda} \, n \tag{4}$$

where $k_{o\lambda}$ is the ozone absorption coefficient in cm^{-1} and (n) is the total ozone content in cm (taken as 0.3 cm)

The first term of Equation (1) represents the optical thickness per unit air mass for all atmospheric constituents at a certain wave length. In fact, the equation represents the attenuation of solar radiation due to scattering and absorption by aerosols.

Substituting $T_{a\lambda}$ from Equation (1) in Angstrom turbidity formula at two wave length (0.425 μm) & (0.47 μm) which are obtained by using filters OG530 and RG630, the turbidity coefficient (β) and the wave length exponent (α) can be calculated.

A Radiation Model for Jeddah under Cloudless Sky

This model was suggested by Iqbal (1983) and recommended for its simplicity and accuracy. The model incorporates separate expressions for direct, diffuse and global radiation.

The direct radiation is given as (Paltridge and Platt, 1976) :

$$I_{n\lambda} = I_{sc\lambda} (T_{o\lambda} \; T_{r\lambda} - \alpha_{w\lambda}) \; T_{a\lambda} \tag{5}$$

where $I_{n\lambda}$ is the direct normal radiation at mean sun-earth distance.

$a_{w\lambda}$ is the absorbtance of direct radiation by water vapor.

$I_{sc\lambda}$ is the solar constant.

$T_{o\lambda}$ is the spectral transmittance of the direct beam due to absorption by the ozone layer.

$T_{r\lambda}$ is the spectral transmittance of the direct beam due to molecular scattering.

$T_{a\lambda}$ is the spectral transmittance of the direct beam due to scattering and absorption by aerosols.

The diffuse radiation can be written as :

$$I_d = I_{dr} + I_{da} + I_{dm} \tag{6}$$

where I_{dr}, I_{da} and I_{dm} are the broadband diffuse radiation on the ground due to Rayleigh scattering, scattering by aerosols and the multiple reflection between the earth's surface and the atmosphere respectively.

The global (direct & diffuse) radiation on a horizontal surface can be written as :

$$I = I_n \cos\theta_z + I_d \tag{7}$$

$$= (I_n \cos\theta_z + I_{dr} + I_{da}) \quad (1/(1-P_g P_a)) \tag{8}$$

where

θ_z is the zenith angle

P_g is the ground albedo usually taken as 0.2.

and P_a is the albedo of the cloudless sky.

Radiation Instruments

A normal incidence pyrheliometer (NIP) manufactured by the Epply Laboratory (USA) is used. It is attached to an electrically driven equatorial mount to follow the diurnal sun track. The sensitivity of this instrument is 8.16×10^{-6} v/w/m^2. It has a temperature compensation for ambient temperature in the range –20°C to + 40°C. Outside these limits, ± 1% correction is needed. As the measurements are incorporated as differences at two wavelengths, the temperature errors can be neglected. Attached to the pyrheliometer, there are three filters. These are characterized by transmitting the wave length from 0.54 to 2.5 microns (OG530), from 0.63 to 2.5 microns (RG630) and from 0.695 to 2.5 microns (RG695). The filters are used for diurnal measurements; at noon and two hours before noon and after noon. Occasionally hourly measurements were taken from sunrise to sunset.

Two Pyranometers are used for measurements of global and diffuse radiation. The two instruments have sensitivity of 9.69×10^{-6} v/w/m^2 and 9.87×10^{-6} v/w/m^2 respectively. Both have temperature compensation for ambient temperature in the range –20°C to + 40°C. Outside these limits, ± 1% correction is needed. Also for the diffuse radiation the correction of the shadow band was made.

The data were recorded on tape cassettes by a CR21X micrologger, manufactured by Campbell Scientific (USA). The data on tapes are transferred to a pc computer, through Campbell Scientific 201 Program.

Results and Discussion

In cloudless days, the turbidity depends on concentration of different constituents of the atmosphere. During any given day, the transmittances due to Rayleigh scattering of air molecules ($T_{r\lambda}$) and by ozone ($T_{o\lambda}$) and by mixed gases ($T_{g\lambda}$) are nearly constant. Thus, the water vapour and aerosols are likely to be the dominant sources of diurnal variations and turbidity.

The Diurnal Variation of Turbidity

The hourly measurements of the direct solar radiation are used to calculate hourly turbidity on a cloudless day, the 18 of May. Figure (1) shows the data collected on that day. The turbidity was (0.1) on the average during the morning hours (0730-1030 L.T) where the wind speed was (1 m/s). Precipitable water was (4.1 cm). In the afternoon hours (1230-1730 L.T), the turbidity increases to about (0.2) when the wind speed increases to a maximum of (5.5 m/s) and the precipitable water to (5.0 cm). The figure also shows that the wave length exponent (α) is inversely related with the turbidity coefficient (β). Figure (2) shows the diurnal increase of turbidity with precipitable water as calculated by Leckner (1978).

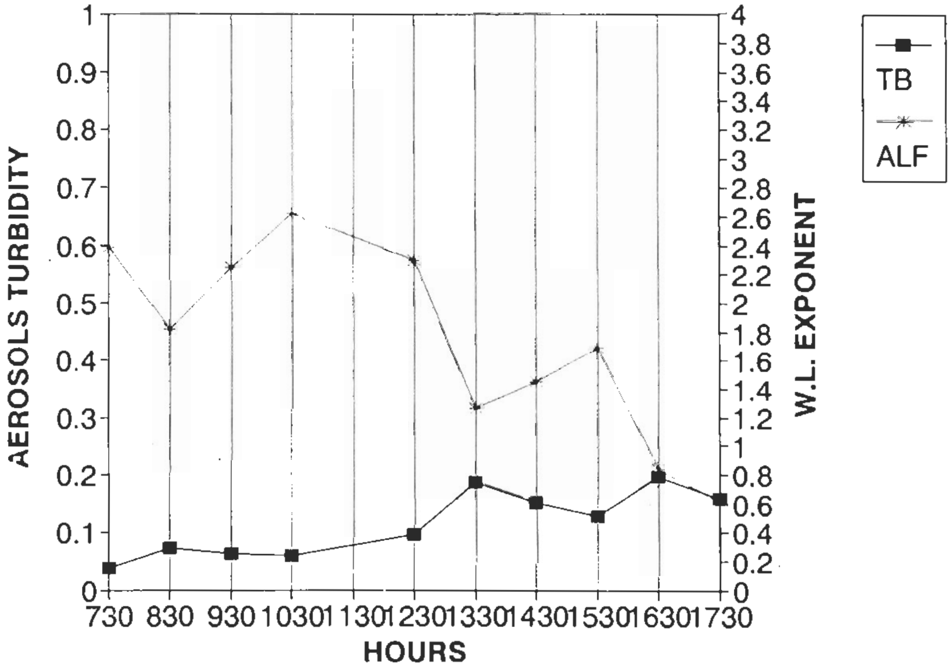

FIG. 1. Diurnal variation of turbidity, Jeddah, 18 May 1993.

The Daily Turbidity

The turbidity measured at noon is considered to represent the daily value. At this time the solar radiation beam passes through the shortest path length in the atmosphere. Thus the solar beam suffers minimal scattering and absorption.

Figures (3-5) show the daily turbidity on the days of measurements in March, April and May 1993 respectively. Figure (3) shows that the maximum turbidity was about (0.4) on 14, 15, 30 and 31 of March 1993. On these days, it is noticed that the wind is

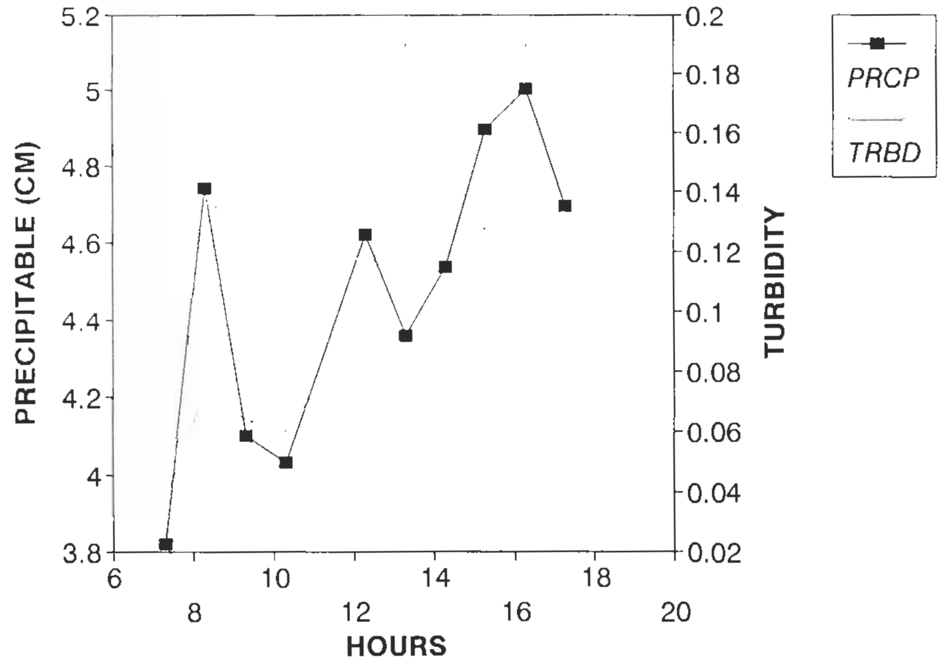

FIG. 2. Comparison between precipitable water and turbidity, Jeddah, 18 May 1993.

NW at an average of more than (3 m/s). At the same time the precipitable water is relatively high (average of 3.5 cm).

Figure (4) shows three day in April on which the turbidity was high, reaching a maximum of 0.85 on 6 April 1993. This day was characterized by southerly winds of more than 6 m/s and high precipitable water (4.2 cm). The other two days (7 and 23 April), also have moderate wind and high precipitable water vapour. Figure (5) shows two turbid days (9, 10 May) on which the turbidity reaches (0.5) when wind and precipitable water conditions were appropriate in direction and magnitude as other turbid days in April.

Estimation of Radiation Components by the Model

(a) Direct radiation

Figure (6) shows the direct radiation normal to the sun (I_n) at noon (1200 L.A.T) for 13 days of spring (March, April and May, 1993). On these 13 days of the experiment, Julian days 69 and 85 (10 and 26 of March), 94, 114, 116 and 117 (4, 24, 26 and 27 of April) and 126, 128 and 138 (6, 8 and 18 of May) were clear days. Turbid days were 73 (14 March), 113 and 118 (23 and 28 of April). One severely turbid day was 96 (6 April). The average calculated direct radiation is 8% over estimation of the measured radiation with a maximum of 15% for individual days. Differences of the same order are noticed in the diurnal change of this parameter on 18th May 1993 (Fig. 7). Average difference averaged (12%) is noticed between 0700 and 1200 L.T.

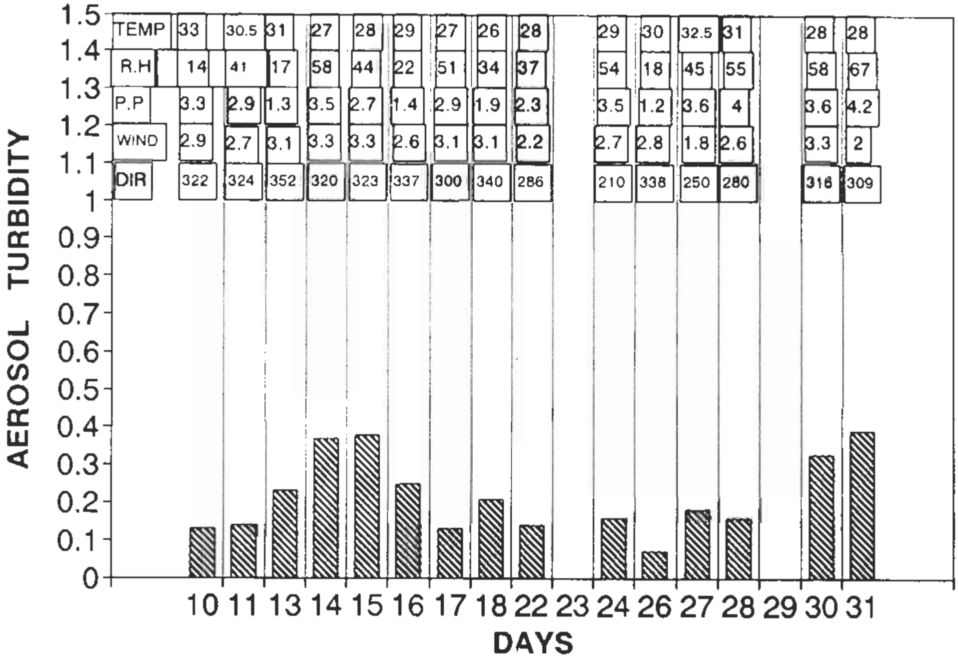

FIG. 3. Daily variation of turbidity at noon, Jeddah, March 1993.

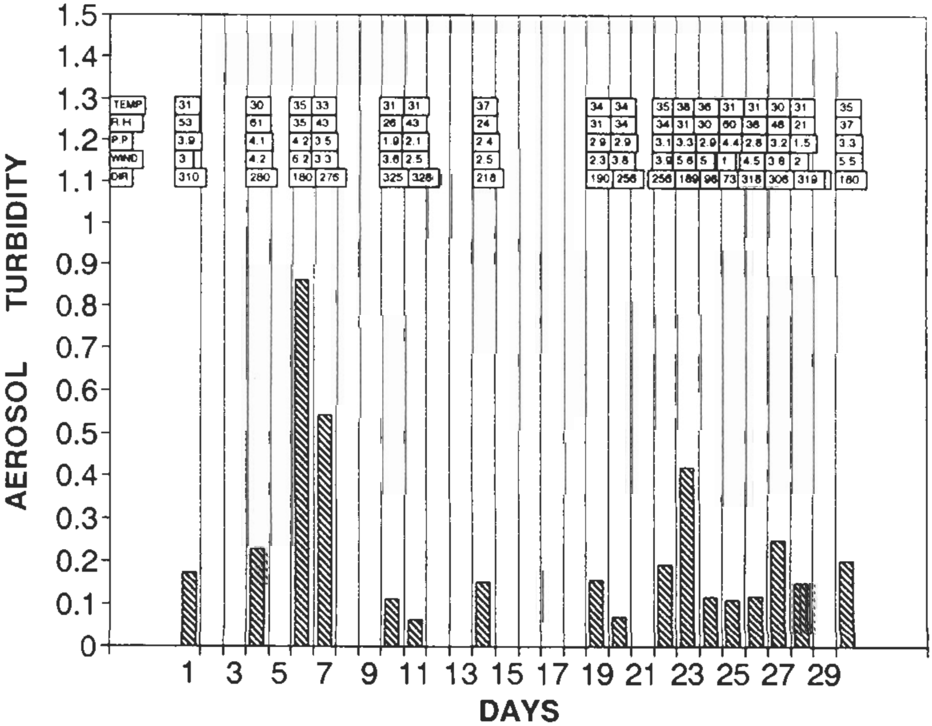

FIG. 4. Daily variation of turbidity at noon, Jeddah, April 1993.

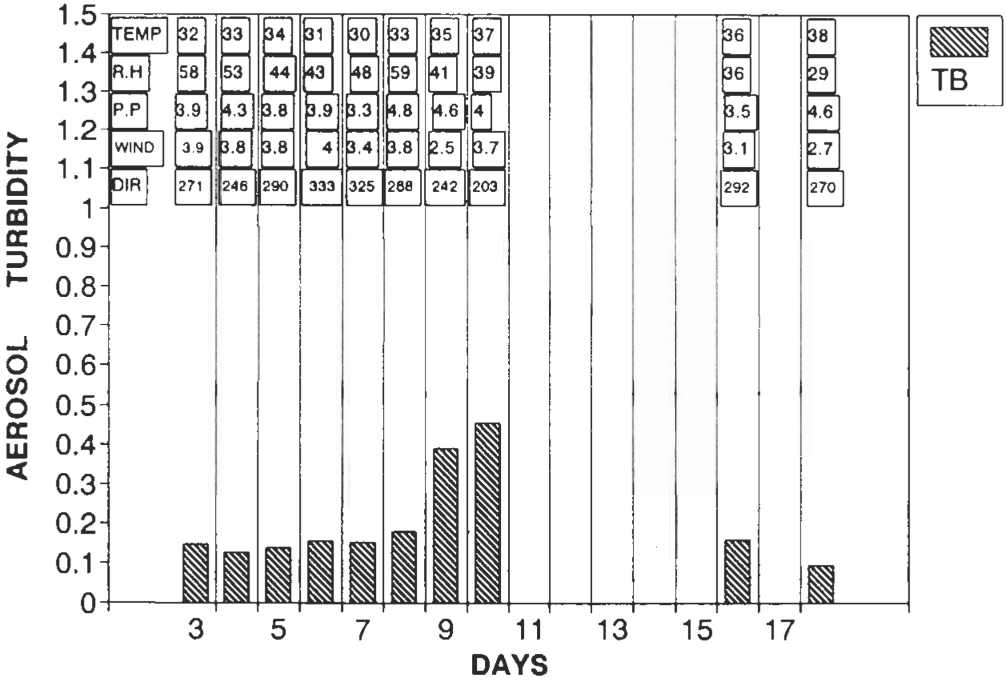

FIG. 5. Daily variation of turbidity at noon, Jeddah, May 1993.

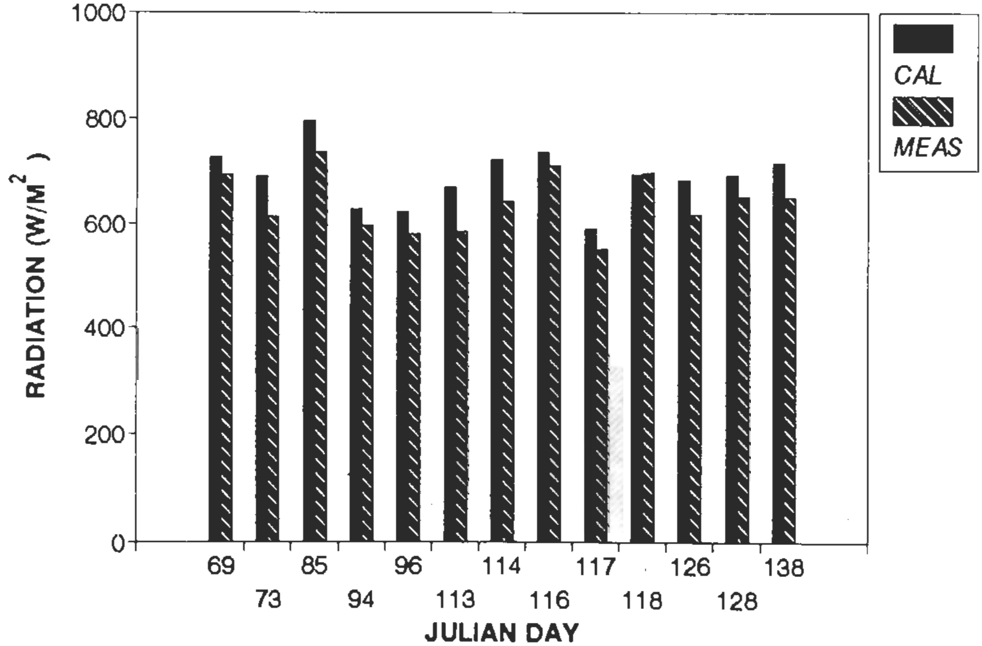

FIG. 6. Calculated and measured direct radiation at noon, Jeddah, 10 March – 18 May 1993.

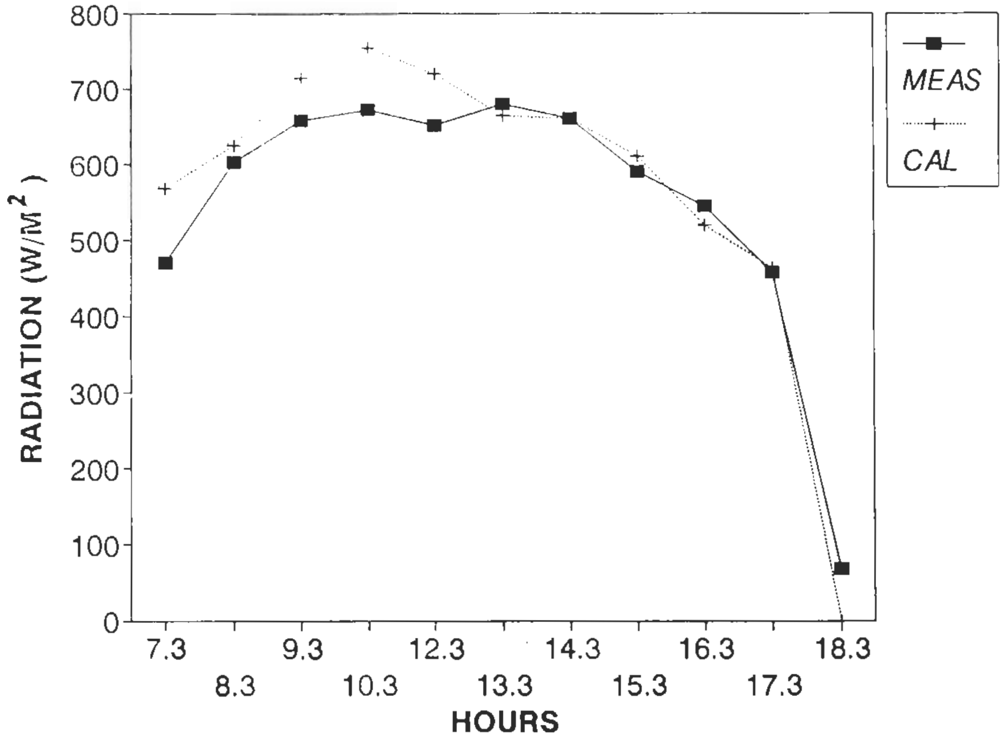

FIG. 7. Calculated and measured diurnal values of direct radiation, Jeddah, 18 May 1993.

(b) Diffuse radiation

The model underestimates the diffuse radiation. This is shown in Fig. (8) at noon (1200 L.A.T). The diffuse radiation is obtained as difference between global and direct radiation. The measured diffuse radiation is used to check the calculated values as measurements are not continuous. The average difference between the measured and estimated values is 15% with a maximum of 20%. It is suggested that the transmittance due to aerosols (T_a) is underestimated by the model as the equation considers (β) equals 0.5 (Iqbal, 1983). This is reflected directly on the diffuse radiation due to Rayleigh (I_{dr}) and multiple reflection (I_{dm}). Also, atmospheric albedo is affected by the underestimation of (T_a).

Figure (9) shows a comparison between hourly calculated and measured diffuse radiation on 18 May 1993. The maximum difference also occurs at noon. As the diffuse radiation is a small component of the global radiation so the error in its estimation does not reflect error of the same order of magnitude on the global value. The direct radiation plays more important role in the difference between the estimated and measured global radiation.

(c) Global radiation

Figure (10) shows the calculated and measured global radiation for all the previously mentioned days of the experiment at noon. The calculated value is over estimated by average of about 5% and maximum of 10% on individual days. Figure (11) shows the

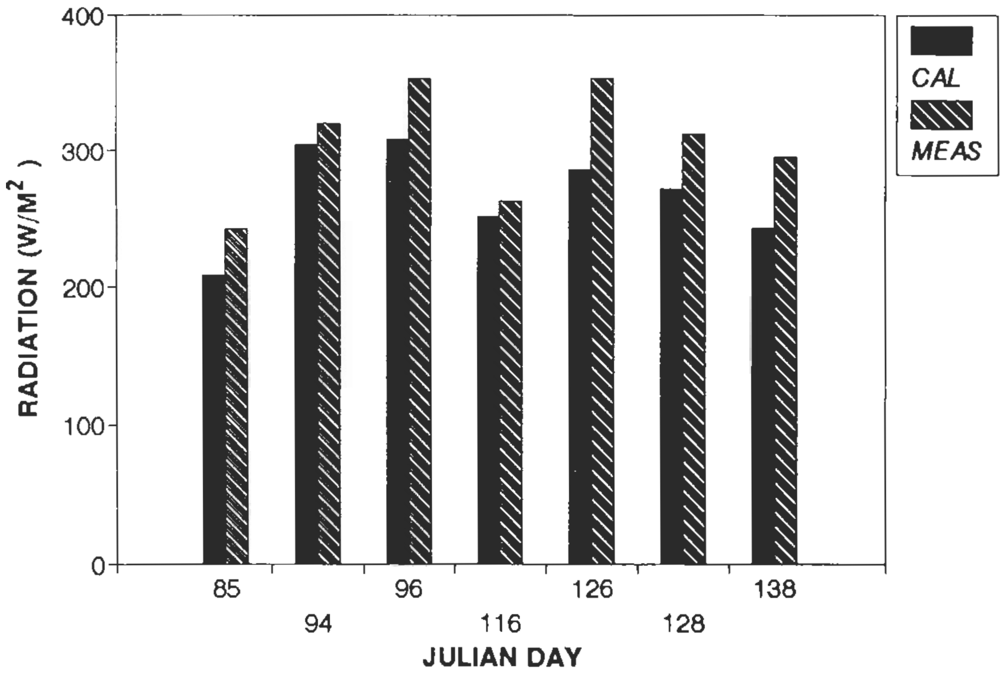

FIG. 8. Calculated and measured diffuse radiation at noon, Jeddah, 10 March – 18 May 1993.

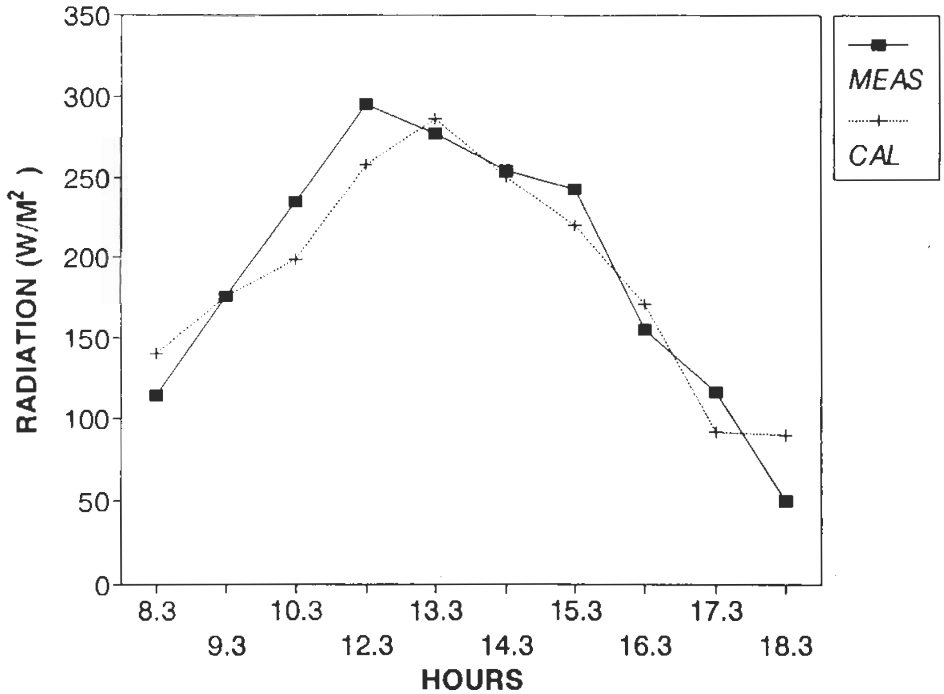

FIG. 9. Calculated and measured diurnal values of diffuse radiation, Jeddah, 18 May 1993.

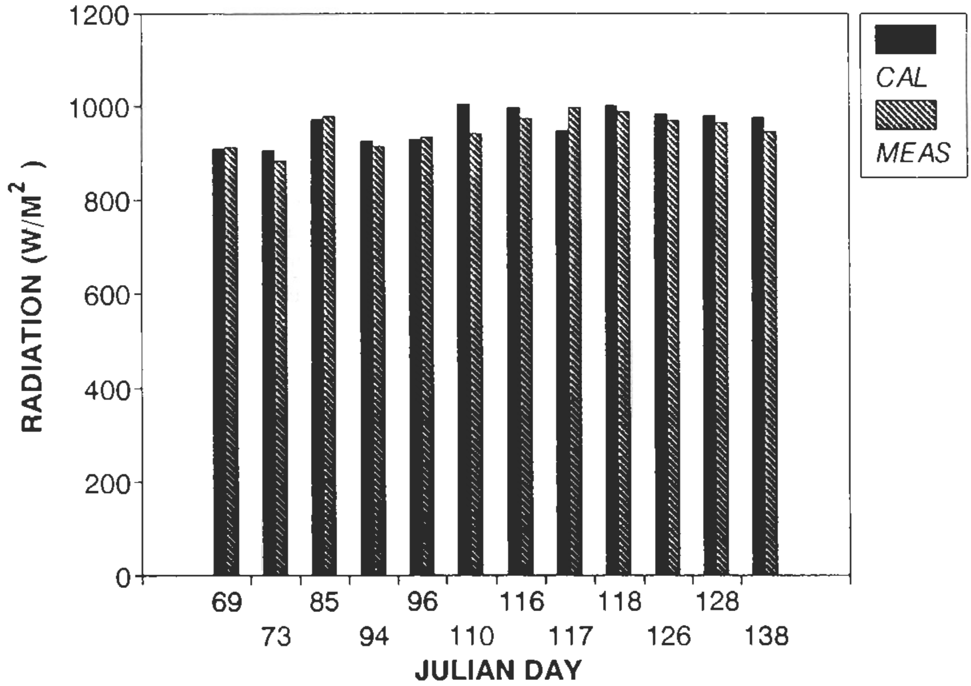

FIG. 10. Calculated and measured global raadiation at noon, Jeddah, 10 March – 18 May 1993.

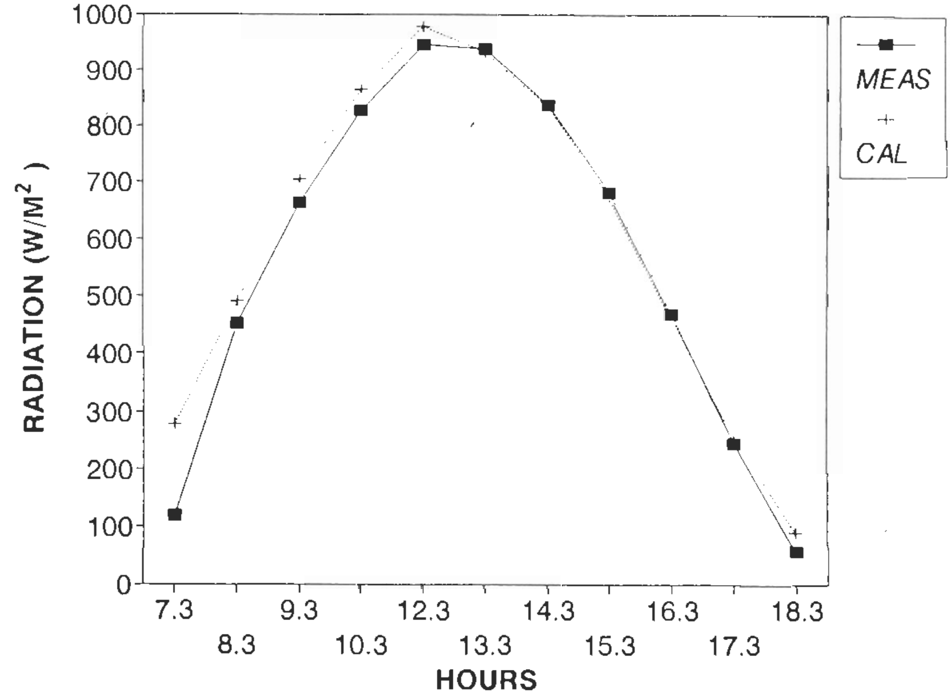

FIG. 11. Calculated and measured diurnal values of global radiation, Jeddah, 18 May 1993.

comparison between the hourly calculated and measured global radiation on 18 of May 1993. Differences of the same order are noticed.

Conclusion

It was possible to estimate the turbidity over Jeddah on cloudless days in spring. The average value of the coefficient of turbidity was (0.18) reaching as high as (0.9) on dusty days, when southerly strong winds prevail over Jeddah. The diurnal variation showed turbidity increase in the afternoons. The model used for estimation of the global radiation gave good overall results and, with some improvements, could be used for estimation of radiation components over Jeddah.

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تقـــدير العـــكاريـة وإشعـــاع القبـــة السماويـة فوق مدينـة جـــدة في فصـــل الربيـــع

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المستخلص . تم تقدير العكارية لمدينـة جـدة خلال فصل الربيع (مارس - أبريل - مايو ١٩٩٣م) ، حيث أخذت قياسات الإشعاع الشمسي المباشر وإشعاع القبة السماوية والإشعاع المتشتت في الأيام الصافية الخالية من السحب . وتم استخدام نموذج عددي لتقدير مركبات الإشعاع الشمسي ، فأظهرت النتائج أن العكارية كانت أكبر مايمكن خلال شهر أبريل مصاحبة لرياح جنوبية إلى جنوبية غربية قوية . وقد بلغت قيمة معامل العكارية (٠,٩) يوم ٦ أبريل ، وهو من الأيام شديدية العكارية . كذلك وجد أن العكارية تزداد خلال ساعات النهار لتصل إلى أكبر قيمة لها عند الظهيرة وتستمر إلى مابعد العصر . كما وُجد أن متوسط العكارية لفصل الربيع فوق مدينة جدة حوالي (٠,١٨) ، وأن النموذج المستخدم لتقدير إشعاع القبة السماوية يصل إلى دقة (١٠٪) ، الأمر الذي يعطي الثقة أنه يمكن تقدير هذا العنصر الهام بالدقة الكافية في كثير من التطبيقات التي تستخدم الإشعاع الشمسي ، عندما لا توجد قياسات فعلية له .