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Reaction of radiometric parameters to atmospheric pollution : Part I — Variation over time

V. DESIKAN, V. R. CHIVATE and V. V. ABHYANKAR

Instruments Division, Meteorological Office, Pune

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सार——औद्योगिक विकास के अभियान के कारण औद्योगिक प्रगति के साथ-साथ बड़े पैमाने पर शहरीकरण भी हो रहा है इस कारण बड़ी मात्रा में फैले हुए कण और गैसीय पदार्थ वायुमंडल में जमा हो जाते हैं। वायुमंडल का संतुलन बनाए रखने की क्षमता के अत्याधिक दुरुपयोग से पृथ्वी-वायुमंडल प्रणाली का ऊष्मा बजट निश्चय ही गड़बड़ा जाएगा । वायुमंडल के विकिरणमाप, दीर्घ-अवधि जलवायु परिवर्तनों की प्रवृत्ति के संकेत पहले दे देते हैं। हालांकि प्रदूषकों के अधिक फैलाव के कारण भूमंडलीय विकिरण अपावरण संभवतः परिवर्तन की स्पष्ट सूचना नहीं दे सकेगा। विसरित विकिरण अपावरण और सीधा सौर प्रकाश वायुमंडलीय परिस्थितियों में परिवर्तन से जल्दी प्रभावित हो जाते हैं। आर्द्रता, मृदा-नमी और बादल जैसे विभिन्न नियंत्रक कारकों का स्थलीय विकिरण ऊर्जा पर भिन्न-भिन्न प्रभाव पड़ता है और इस ऊर्जा में परिवर्तन धीरे-धीरे ही होता है जिससे किसी स्थान की जलवायु को प्रभावित करने में बहुत समय लगता है। किन्तु सीधा सौर प्रकाश तथा कुल पार्थिव विकिरण ऊर्जा में बढ़े हुए विसरित अवयव से सामान्य प्रवृत्ति का पता चल जाता है। अनुक्रियाएं स्पष्ट तौर से निश्चित अर्थ को प्रकट करती हैं और विशेषकर पुणे में ये सही सिद्ध हुई जहां पिछले पंद्रह वर्षों के दौरान औद्योगिक गतिविधियां असाधारण रूप से बढ़ी हैं।

ABSTRACT. The drive for industrial development has led to large scale urbanisation and resulted in the injection of good amount of suspended particles and gaseous substances into the atmosphere. The over-abuse of the capacity of the atmosphere to sustain the equilibrium is bound to disturb the heat budget of the earth-atmosphere system. Radiometric parameters of the atmosphere give an early indication of the trends in the long-term climatic changes. While the global radiant exposure is not likely to show perceptible changes due to the increased scattering by the pollutants, the diffuse radiant exposure and the direct solar irradiance respond quickly to the changes in the atmospheric conditions. Various controlling factors like humidity, soil moisture and clouds have different effects on the terrestrial radiant energy and the changes in this energy occur slowly and take long time to affect the climate at a place. But the general trend is indicated by the increased diffuse component in the direct solar irradiances and in the net outgoing terrestrial radiant energy. The responses are clearly indicative, particularly at Pune, where the industrial activities grew at a phenomenal rate during the past fifteen years.

Key words — Radiation components, Variation with time, Clear reaction in radiation parameters.

1. Introduction

The solar irradiance, in its passage through the atmosphere, gets attenuated by scattering and absorption processes. Radiometric studies made at the earth's surface mainly explore the combined effect of these two processes. The attenuation factor is a function of the aerosol content of the atmosphere. The rapid industrialisation and the consequent urbanisation has led to the injection of various aerosol particles into the atmosphere, resulting in the ever increasing extinction of the incoming solar irradiance. Junge (1977) has discussed various types of aerosols and their effects on the radiative transfer. For studying the total attenuation effects, the contribution of individual constituents and their preponderance are not quite relevant. However, the contribution by the location, the atmospheric transport mechanisms and removal processes of the injected aerosols are very important. Fine particulate matter, dust and other constituents, because of their stability and negligible fall velocities are probably the most common and persistent air pollutants.

Solar irradiation, particularly in the shorter wavelengths can be used as an index of the attenuating power of the pollutants. This could be demonstrated by comparing the irradiances over an urban area with those over a nearby rural area. However, the pollutants raised over the industrial area spread far and wide into the countryside making such comparisons difficult. But they do indicate the effect of the attenuation over a "developed" area.

The effect of aerosols on radiation is peculiar to each city or region, due to varying industrial and geographical factors. The effect of a city on the solar irradiation has been studied by many; some of the important contributions are by McCormick and Baulch (1962), Chacko *et al.* (1966), Bach (1973), Dogniaux and Sneyers (1972), Fujimoto (1974, 1975), Lal (1973), Mani *et al.* (1973) and Rangarajan (1972). The present attempt gives as Part I — the results of the studies, made at selected locations of various radiation parameters and then in Part II — compares them with other stations.

2. Data and method

Various components of radiant field are being measured systematically in the radiation network managed by India Meteorological Department. The components which are directly indicative of the attenuation effect are:

(1) Global solar radiant exposure (H_g).

(2) Diffuse solar radiant exposure (H_d).

(3) Direct solar irradiance (S).

(4) Turbidity coefficient (β) derived from spectral measurements of direct solar irradiances, and

(5) Net terrestrial radiant energy ($E_l^* \uparrow$).

Pyranometers and Ångström pyrheliometers are used for the collection of data at different stations. Ångström pyrgeometer measures the outgoing terrestrial radiant energy.

The data show large variations from year-to-year due to prevailing sky conditions. Two years data have been grouped and averaged in order to normalise the fluctuations. The periods considered are 1960-61 (I), 1965-66 (II), 1970-71 (III), 1975-76 (IV), 1980-81 (V), and 1985-86 (VI). To eliminate the masking effects of the clouds, only cloudless sky data have been considered. The results are discussed in two parts: (*i*) the effects of particulate matter at the same place over several years, and (*ii*) the comparison of these regimes between two pairs selected stations.

3. Variations at a place with time

There has been developmental activity in various spheres at different locations in India since the dawn of independence of the country. Though this had led to considerable improvements in living standards, the population growth which has not been contained well has contributed to the increase in the particulate matter in the air. The unbridled destruction of forest cover and the urbanisation activities in the same loation have been a major source of pollutants in the environment. This is bound to cause variations in the radiant energy fields, which, in turn, will affect the ambient living conditions seriously though in its own time scale. It is proposed to study, here, the variations over a period of three decades at about seven stations in India.

3.1. *Jodhpur* (*Fig. 1*)

Located in the eastern periphery of the Thar Desert, Jodhpur has more of natural dust load, higher concentration of it occurring during the pre-monsoon season. The annual incidence of global radiant exposure (H_g) steadily decreases from 23.24 MJm^{-2} per day during 1965-67 to 20.97 MJm^{-2} in 1985-86 amounting to a fall of 10%. The diffuse radiant exposure (H_d), however, increases by 24% during this period from 4.11 MJm^{-2} per day to 5.11 MJm^{-2} per day. The ratio H_d/H_g also shows gradual increase from 0.19 in 1970-71 to 0.24 in 1985-86. The block 1980-81 shows an abnormal increase, 40% in H_d and 0.27 in H_d/H_g, mainly due to the extremely low precipitation during the period 30-40% below normal (Table 1). The scattered irradiance (H_d) generally shows a decrease in January and February due to the winter rains and then a gradual increase during the pre-monsoon periods, increasing by about 160% from about 3.72 MJm^{-2} per day in February to 9.63 MJm^{-2} in May. The diffuse component accounts for 35-45% of the global radiant exposure at this time. This increases to even beyond 50% during June and July due to the dust load injected into the atmosphere by dust/sand storms.

The direct solar irradiance (S) gives a more direct indication of the transmission properties of the atmosphere. A high annual value of 843.4 Wm^{-2} received around noon during 1979-71 had steadily decreased to 702.2 Wm^{-2} during 1985-86, amounting to a drop of 17%. The winter rains in January-February cleanse the air to some extent, resulting in a higher transmission condition, more than 900 Wm^{-2} is received at the surface. This gradually decreases by more than 12% to 788 Wm^{-2} in June. Due to scanty rains in 1980-81 (30-40% deficient), it was only 855.2 Wm^{-2} in February and 558.0 Wm^{-2} in June — a decrease of about 35%. The cleansing of air during monsoons also was not much during this block (rainfall deficit being more than 50%), September receiving 734.7 Wm^{-2} as compared to 1021.1 Wm^{-2} during 1970-71. The turbidity coefficient (β) which is a direct indicator of dust load increased by 60% from 0.045 during 1970-71 to 0.072 during 1985-86. The dust loading increases by more than 60 per cent from the clearest month, February to March-April. Even the post-monsoon value of 0.034 of 1970-71 has risen to 0.045 in 1985-1986.

A study of the variations in the net outgoing terrestrial radiant energy ($E_l^* \uparrow$) (Fig. 1 also gives a clear trend in the changes in the field. The large decrease in $E_l^* \uparrow$) is consistent and perhaps even alarming. $E_l^* \uparrow$ had dropped by about 19%. A poor rainfall activity only increases the absorption of this radiance by the suspended dust particles in the atmosphere as evidenced by 42.2 Wm^{-2} in July of 1980-81 in comparison with 67.1 Wm^{-2} during 1985-86 (37%).

3.2. *Delhi*

Delhi gets the atmosphere loaded with pollutants— natural ones blown from the Rajasthan deserts and man-made ones produced *in situ*. The variations shown in H_g over more than two decades are not much (Fig. 2), decreasing only by about 3%. However, the diffuse radiant exposure H_d increased by about 30% from 5.26 MJm^{-2} per day during 1959-61 to 6.85 MJm^{-2} in 1985-86. Even during the 1975-76 block, which received about 40% excess rainfall over the normal (Table 1), H_g increased by 5% over that of 1959-61 block while H_d showed an increase of 19% to 6.26 MJm^{-2} per day. The ratio of H_d to H_g was 0.24 in 1959-61 and it rose to 0.32, the increase being about 33%.

H_d formed 24% and 39% of H_g in May and June respectively during1959-61. This rose to 36% and 45% respectively during 1985-86. On a cloudless sky H_d can be individual cases reach up to 60% over Delhi before the monsoon rain washes the dust down.

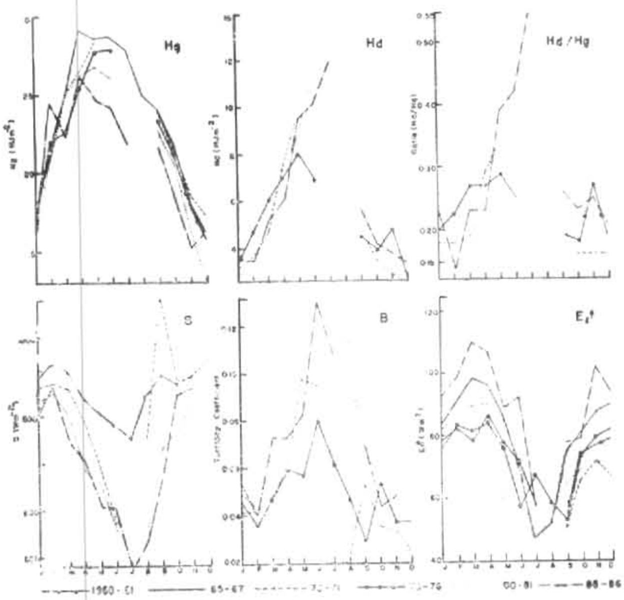

Fig. 1. Variations in radiometric parameters at Jodhpur

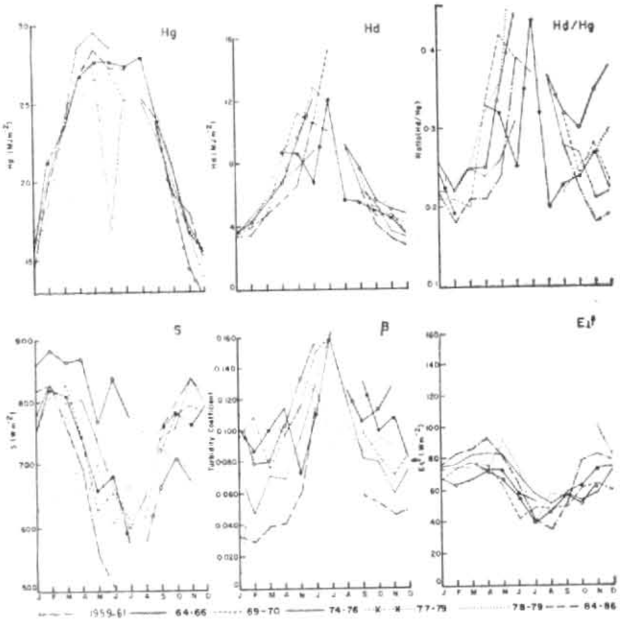

Fig. 2. Variations in radiometric parameters at New Delhi

TABLE 1

Normals of monthly rainfall (mm) at the selected seven stations

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Jodhpur	7.3	5.1	1.9	2.2	6.4	30.9	121.8	145.5	47.4	6.8	3.3	1.5	380.1
New Delhi	24.9	21.8	16.4	6.8	7.9	65.0	211.1	172.9	149.7	31.2	1.2	5.2	714.2
Bhavnagar	2.5	0.5	3.4	12.5	6.2	73.7	242.8	152.0	121.9	37.8	7.3	0.2	660.8
Ahmedabad	3.9	0.3	0.9	1.9	4.5	100.0	316.3	213.3	162.8	13.1	5.4	0.7	823.1
Nagpur	15.4	1.9	24.5	20.2	9.9	174.3	351.5	277.1	180.5	61.6	8.7	1.7	1127.3
Pune	1.9	0.3	3.1	17.6	34.7	102.8	186.8	106.4	127.3	91.9	37.0	4.9	714.7
Calcutta	13.2	21.8	29.6	49.8	134.6	263.2	320.1	318.1	252.7	134.2	29.2	3.6	1570.1

The values of direct solar irradiance (S) decreased by 18% over the period from 823 Wm^{-2} in 1959-61 to 679 Wm^{-2} in 1985-86. Even during 1975-76, the values were less by 10%. Unlike Jodhpur, Delhi has a higher transmission of S in November. And it has reduced from 840 Wm^{-2} during 1965-66 by 20% to 672 Wm^{-2} in 1985-86. The peak value normally registered in February, however, shows only a 6% decrease from 889 Wm^{-2} to 832 Wm^{-2}. Fig. 2 shows the effect of induction of dust load from the west when the high value of 'S' of April drops by more than 12% in May except during 1978-79. The decrease in May is about 28% over the decade, while it is about 40% in June. These changes are reflected well in the variations of β. The change in the first five years itself amounts to 60% increasing from an annual average of 0.055 to 0.089. In 1985-86, it was 0.114, an increase of 107% over the 1959-61 block. The variations in the individual months were, however, high because of the then prevailing conditions, but the increasing trend in the atmospheric pollution is evident.

The generally low values of $E_l^* \uparrow$ indicates the extent of radiation trapped in the atmosphere (Fig. 2). The reduction in $E_l^* \uparrow$ over the two decades is of the order of 18%. That the deterioration of the Delhi atmosphere is sharp, is still very much evident despite the fact that the site of measurements was changed from the centre of Delhi to extreme southwest. The change was necessitated by the increasing poor exposure conditions. The earlier site was in the windward direction of the Indraprasth Thermal Power Station.

3.3. *Ahmedabad*

This is located outside the deserts and in the semi-arid regions south of the deserts. Ahmedabad is an industrialised place since long. The global radiant exposure H_g is of the order of 22 MJm^{-2} (Fig. 3), the value having decreased marginally by about 8%. H_d also does not show much increase over the years unlike Delhi or Jodhpur. Actually the 1975-76 and 1980-81 blocks show a decrease in H_d amounting to 17% and 7% in respective blocks. The large decrease of H_d in 1975-76 may be ascribed to the copious rainfall more than 55% in excess received during the block (Table 1), resulting in washing out of the particulate matter. The ratio H_d/H_g is of the order of 0.22 over the two decades. The winter months record a low ratio 0.17-0.19 and the pre-monsoon May a high value of 0.32-0.37. Surprisingly the extremely low rainfall

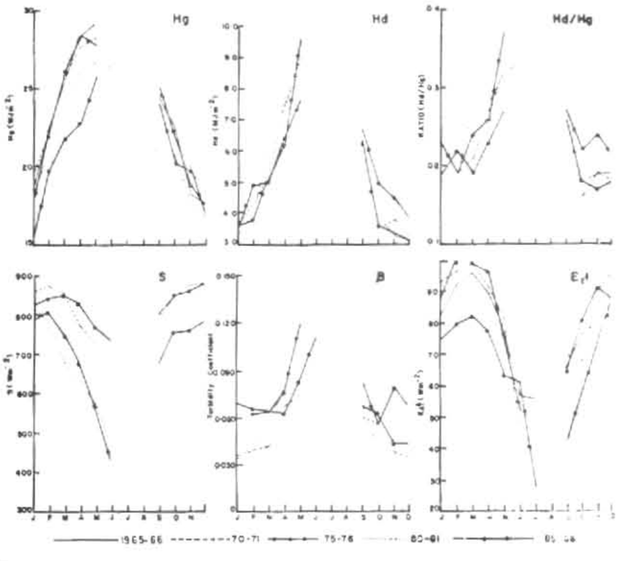

Fig. 3. Variations in radiometric parameters at Ahmedabad

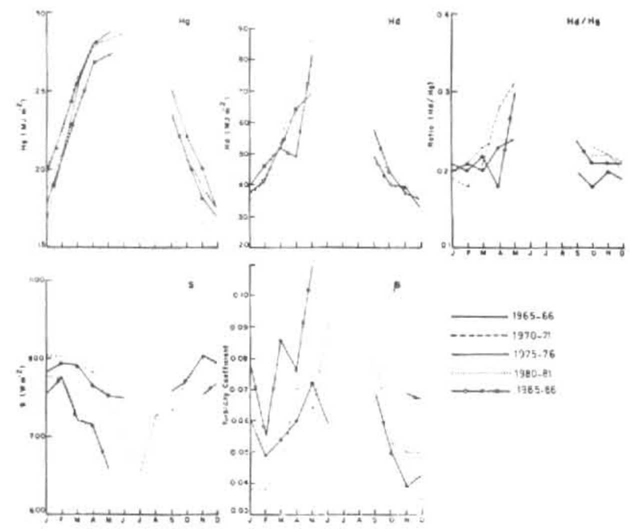

Fig. 4. Variations in radiometric parameters at Bhavnagar

TABLE 2

Seasonal (percentage) differences over the period 1970-71 to 1985-86

Station	Winter					Pre-monsoon					Post-monsoon				
	S	H_g	H_d	β	$E_l^* \uparrow$	S	H_g	H_d	β	$E_l^* \uparrow$	S	H_g	H_d	β	$E_l^* \uparrow$
Jodhpur	−7	+1	+7	−31	+3	−7	−9	−5	+10	+1	−4	−17	+25	+32	+10
New Delhi	+6	−8	+18	+1	−5	−9	+4	−7	+10	−4	−12	−8	+14	+57	−8
Bhavnagar	−7	−4	+4	+67	—	+18	−4	−16	−52	—	−7	+11	+5	+47	—
Ahmedabad	−9	−12	0	+94	−17	−16	−13	−4	+41	−18	−12	−2	+29	+46	−17
Nagpur	+3	−7	−10	0	+5	−1	−5	+8	−5	+31	0	−8	+11	−4	−9
Pune	−5	−7	+8	+26	−22	−16	−7	−5	+11	−23	−10	−16	+9	+47	−29
Calcutta	−22	−9	−9	+35	+14	−37	−12	−7	+67	+41	−30	−9	−4	+56	+38

(94% deficit) of 1970 has not contributed much to increase in H_d even during the 1970-71 period.

The direct solar irradiance S (Fig. 3), however, shows large decrease 13-14% over the period. February has only 7% lower incidence in 1985-86, when compared with 1970-71 value. The steepest fall is, however, in May with 23% lower irradiance. The effect of urbanisation is only marginal, it appears, over the period from 1970-71, perhaps, caused by the cleansing of the skies due to the very good rains received during 1975-76. The turbidity, however, gives a much clearer picture (Fig. 3). The annual mean of 0.046 during 1970-71 has almost doubled to 0.086 after a decade and a half. The increases in the winter months are more than 100% during the period. Of course, the increase is not high during the premonsoon period. The irradiance value has a consequence decreased from an average high value of 879 Wm^{-2} during 1970-71 to 811 Wm^{-2} during 1985-86.

The outgoing net terrestrial radiant energy $E_l^* \uparrow$ does not show much variation (Fig. 3) during the period 1965-76. The later periods 1980-81 and 1985-86 show sharp decrease from 82 Wm^{-2} to 72 Wm^{-2} on an average during 1980-81 resulting in about a 13% reduction. The post monsoon season in each block shows high variability depending on the precipitation during the preceding monsoon. However, the steep reduction after 1980-81 is unmistakable, *i.e.*, only a smaller amount of the terrestrial radiant energy escapes from the earth.

3.4. *Bhavnagar*

Located about 130 km south of Ahmedabad, Bhavnagar has the Bay of Cambay to the east. The place has less industrial activity but has a number of salt farms on its coast. Fig. 4 gives the variations of different parameters. Bhavnagar does not make measurements of net outgoing terrestrial radiant energy. The variations in H_g and H_d are marginal, depending upon the rainfall distribution during the monsoon season. On an average 22.60 MJm^{-2} of global radiant exposure is received. H_d accounts for 4.88 Wm^{-2} amounting to 22% of H_g. The maximum of H_g is in May and the minimum is received during December—January period. While more than 27% of H_g is due to H_d in May, it is still high at 22% in November.

Like global and diffuse components of radiant exposure which do not show any marked change during 1975-76, when Bhavnagar had an excess of 42% over the average rainfall (Table 1), the direct solar irradiance also does not indicate any large change in the annual value (860 Wm^{-2} in 1970-71 to 854 Wm^{-2} in 1975-76).

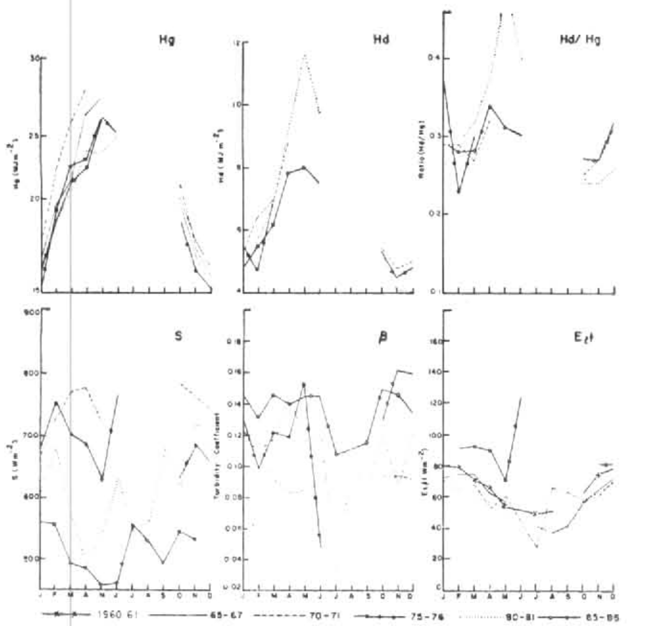

Fig. 5. Variations in radiometric parameters at Calcutta

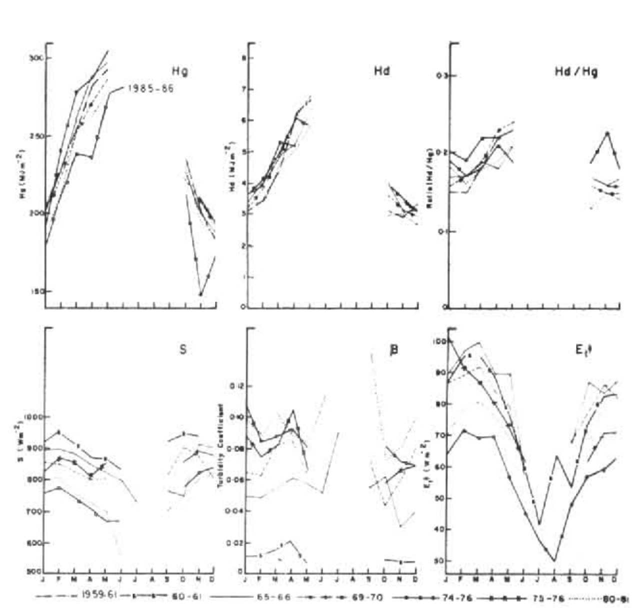

Fig. 6. Variations in radiometric parameters at Pune

A very interesting feature is the near unform high irradiance level well above 800 Wm^{-2} throughout the period during 1975-76. The difference is hardly 13% between the maximum and the minimum. This difference between the maximum and minimum irradiances was, however, 33% both during 1970-71 and 1980-81 blocks of years. The annual average during the late periods is about 740 Wm^{-2} as compared to annual average of 854 Wm^{-2} during 1975-76.

Ångström turbidity coefficient β (Fig. 4) is surprisingly quite high with an annual average of over 0.050. A possible explanation could be that salt provides the hygroscopic nuclei for the growth of condensation nuclei, which in turn constitute the aerosol particles. The increase in 'β' is of the order of 31% in 1980-81 and 50% in 1985-86. The November-December values during 1975-76 and 1980-81 were quite low-less than 0.040. A check with rainfall data indicates that the rains occurred well into October-November in both cases.

3.5. *Calcutta*

Calcutta has a regime of moist air and a large and heavily populated urban area with heavy industrial installations. Here again like Ahmedabad there is little variation (Fig. 5) over the years, either in the values of H_g or H_d. Calcutta receives about 22.0 MJm^{-2} as global irradiance of which about 6.3 MJm^{-2} is accounted for by diffuse component, amounting to 30%. Unlike other places, February and March have higher incidence of diffuse irradiance, mostly because of the prevalence of fog and consequent lower transmission. Here again only beyond 1980, does one find a lower H_g, but by 7% only. The post monsoon season has the lowest diffuse component, about 24 to 27%. This increases to more than 30% by March. The increase reaches a maximum of 40% or more by May, despite good showers during the periods.

The direct irradiance, however, is seen to be quite low, October recording an average of 785 Wm^{-2} during 1970-71 (Fig. 5). The annual mean of 746 Wm^{-2} reduces drastically further by 16% to 516 Wm^{-2} in 1985-86. Monthly averages did not even reach 600 Wm^{-2}. Here again the lowest reduction is during December-January, being around 20% of 1970-71 level and it is as high as 37% during the pre-monsoon period. The turbidity coefficient β computed by assuming the wavelength exponent to be 1.3 (Rangarajan 1972) gives an average value of 0.088 during 1970-71, rapidly increases by 39% to 0.122 (Fig. 5). The mean for the block 1985-86 is 0.136. These increases are inspite of the normally well distributed rainfall during the periods (Table 1). The mean β for the period November-June of the last block is more than 0.147, giving an indication of the atmospheric condition for most part of the year over Calcutta.

The net terrestrial radiant energy $E_l^* \uparrow$ was on an average 65 Wm^{-2} during 1960-61 and this decreased by about 12% to 57 Wm^{-2} during 1980-81. However, the 1985-86 block recorded a phenomenal increase of 35% to 87 Wm^{-2}, much higher than the 1960-61 level. This period had a heavy rainfall distribution during the monsoons. This type of atmospheric reaction was not depicted during the 1970-71 period when Calcutta had an excess rainfall of more than 23% excess rains as compared to the 17% excess during 1985-86. The annual march shows invariably a decreasing trend from January to June except during 1985-86 when the stray cloudless sky occurred after a severe thunderstorm activity giving a high value of 122 Wm^{-2} for the net terrestrial radiant energy.

3.6. *Pune*

Pune receives, on an average, about 21.8 MJm^{-2} of H_g and well above 4.0MJm^{-2} of H_d. This means that about 19% H_g is due to H_d. There is, however, a large difference between the maximum global irradiance

TABLE 3

Annual percentage variation in radiometric parameters

Station	S	H_g	H_d	β	$E_l^* \uparrow$
Jodhpur	—14	—5	—48	60	—1
New Delhi	—10	—2	—30	+11	—2
Bhavnagar	—6	0	4	—33	—
Ahmedabad	—13	—8	—20	74	—14
Nagpur	—6	—4	—16	—2	—17
Pune	—11	—6	—1	23	—30
Calcutta	—31	—4	—1	—55	—49

(28.92 MJm^{-2}) in May and the minimum in December-January (18.80 MJm^{-2}) (Fig. 6). Diffuse maximum irradiance is, however, more than double of the minimum. A striking feature is the drop in diffuse irradiance in October by almost half of the pre-monsoon values of more than 6.0 MJm^{-2}. Since global irradiance also falls significantly instead of increasing (mainly due to vast differences in the angles of incidence and duration of the day) the ratio H_d/H_g does not reflect these abrupt changes (Fig. 6).

Fig. 6 shows the direct irradiance field over Pune during the various blocks of years. A high February average of 953 Wm^{-2} of 1960-61 could not be more realised over Pune. The 1985-86 value for February has reduced by about 19% to 776Wm^{-2}. Similarly the high 940 Wm^{-2} of the post-monsoon period during 1960-61 has dropped by about 10-15% to less than 850 Wm^{-2}. A consistent feature is the higher irradiances in February over January or March, perhaps, due to drier atmospheric conditions during February. On an annual scale the 913 Wm^{-2} of 1960-61 has come down by 17-18% to 750 Wm^{-2} or less during 1985-86.

The decreasing trend in the annual values of S is halted temporarily during 1975-76, perhaps, due to the efficient cleansing of the sky by the excess 50% monsoon rains (Table 1). The subsequent block 1980-81 also had 30% excess rainfall, but it was well distributed. This, however, could not arrest the decreasing trend in S following the rather explosion of industrial and urbanisation activities of latter seventies and eighties. The highest recorded average value is only 827 Wm^{-2} in December.

It is the value of turbidity coefficient β that shows (Fig. 6) the changes very clearly. β was having a nominal value of 0.012 in 1960-61 (near dust free conditions) and in a 5-year period the annual mean had jumped more than fourfold to 0.054. The relentless addition of pollutants into the air is clearly seen in the ever increasing β value. It has now become more than 7-8 times that of the 1960-61 level. Even with reference to the 1965-66 level, the present day (1985-86) values are at least 60% higher.

The above readings are again supported by a study of net terrestrial radiant energy $E_l^* \uparrow$. After an initial increase up to 1965-66 about 13%, $E_l^* \uparrow$ started decreasing. In 1980-81 it was 7% lower than 1960-61 and 17% lower than the 1965-66 level. The drop further in 1985-86 is rather steep, 26% with reference to 1960-61 and 20% with reference to 1980-81 values. The high losses of 95 Wm^{-2} has reduced to 70 Wm^{-2} in 1985-86, amounting to a reduction of more than 26%. The trend is evident and the reaction to it by the atmosphere may be gradual but is inevitable.

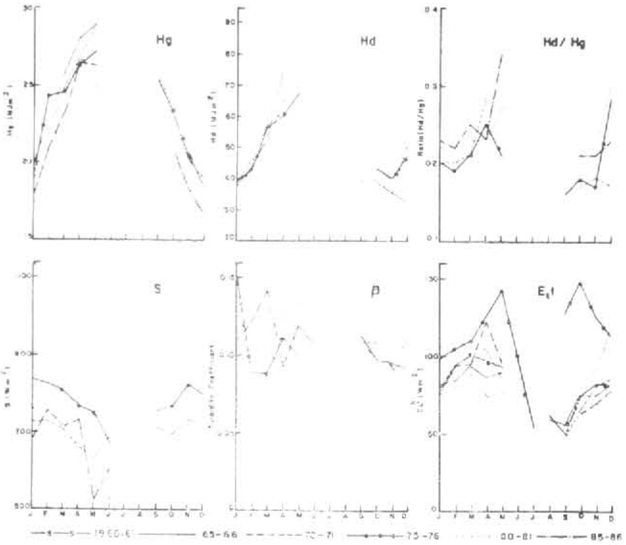

Fig. 7. Variations in radiometric parameters at Nagpur

3.7. *Nagpur*

On an average 22.25 MJm^{-2} are received per day as H_g and 4.84 MJm^{-2} as H_d (Fig. 7). Here again the incident global and diffuse radiant exposure had been nearly constant up to 1975-76 after which H_g had dropped by 10-12% and H_d increased by more than 10%. The diffuse values have been as high as 16% (5.20 MJm^{-2}) in 1985-86 over the 4.50 MJm^{-2} value of 1970-71. H_g values show a steady increase from December through May. However, the overall values of H_g in each month show a decreasing trend over the period from a maximum of 28.82 MJm^{-2} in May during 1970-71 to 26.13 MJm^{-2} in 1985-86. The rise from December to May is however, more significant in H_d. The ratio of H_d to H_g was nearly stable at 0.20 up to 1975-76 and then shifted to 0.24. Curiously, the diffuse component in December is found to be higher than November. The highest proportion of H_d in H_g is seen in April-May.

The direct solar irradiance shows some interesting features (Fig. 7). The annual value increased by 13% from 703 Wm^{-2} in 1970-71 to 794 Wm^{-2} in 1975-76. In 1980-81, it reverted back to 704 Wm^{-2} only to reduce further by another 5% to 666 Wm^{-2} in 1985-86. Rainfall had been near normal or excess and well distributed during all these selected periods. As if the skies have been cleaned nearly off all dusts during 1975-76 high irradiances of the order of 843 Wm^{-2} have been recorded in November and 837 Wm^{-2} in January. The highest recorded in 1970-71 was 735 Wm^{-2} in December and that in 1980-81 was 817 Wm^{-2} again in December. The values in 1985-86 were quite low. The turbidity coefficient β (Fig. 7), however, do not reflect such changes. β values are, on an average, uniformly high, above 0.100. The individual monthly mean

TABLE 4

Seasonal rainfall in percentage during the two blocks

Year	Winter	Pre-monsoon	Monsoon	Post-monsoon	Winter	Pre-monsoon	Monsoon	Post-Monsoon
		Jodhpur				**New Delhi**		
1970	—100	0.0	+50	—100	+47	+123	+5	—74
1971	—100	+571	—24	—59	—44	+98	+33	—76
1985	—100	+939	—67	—34	—85	—55	—3	+152
1986	—71	+542	—37	—72	+129	+66	—67	—100
		Ahmedabad				**Bhavnagar**		
1970	—80	—100	—94	—95	—63	+65	+136	—100
1971	—100	+86	—35	—33	—100	—77	—11	—98
1985	—100	+163	—38	+129	—100	—99	—40	+188
1986	—100	+42	—45	—100	—100	—100	—47	—100
		Pune				**Nagpur**		
1970	—100	—5	—36	—16	+1	+43	+44	—98
1971	—100	—46	—21	—67	+198	+23	—10	+50
1985	—100	—63	—33	+21	+54	—44	—10	+417
1986	—100	—42	—5	—98	+431	—50	—19	—68
		Calcutta						
1970	—74	—29	—2	+55				
1971	+148	+74	+39	+50				
1985	—64	—46	+6	—18				
1986	—44	—5	+47	+79				

values are also high, higher than 0.088. Only November seems to be free of the fluctuations and records the lowest β around 0.093. April to June seem to be surcharged with particulate matter, possibly because Nagpur receives rains in significant amounts from June onwards only.

Fig. 7 gives the net terrestrial radiant energy $E_l^* \uparrow$ over 25 years. The outgoing energy which was on an average 81 Wm^{-2} started decreasing by 8% to 75 Wm^{-2} in 10 years time and suddenly increased to 116 Wm^{-2} by 1975-76. Thereafter, the fall has been very significant, 13% reduction in 1980-81 and 25% in 1985-86 with reference to the peak values of 1975-76. The maximum values of $E_l^* \uparrow$ occurs generally in March. The post monsoon values vary widely, perhaps, depending on the actual lingering moisture in the air up to October end.

4. Conclusions

(*i*) It is seen that the urbanisation and industrialisation at a place affect the radiation field at the place and thus are bound to disturb the thermal budget of the earth-atmosphere system.

(*ii*) At almost all the seven stations considered global solar radiant exposure H_g has been found to be decreasing steadily over a period of 15 years. The degree of the monsoon activity is an important controlling factor on the dust load during the post-monsoon and winter season. Depending on this H_g values slightly vary from block to block, but the trend is clear that H_g slowly decreases. The downward trend in H_g is clearly discernible in Jodhpur.

(*iii*) The diffuse solar radiant exposure (H_d) reacts in the opposite way. H_d shows a steady increase over the years at each place. Even though Jodhpur is not affected much by industrial pollution, the increase in H_d is as high as 25%, perhaps, an effect of urbanisation.

(*iv*) The changes in H_g are not very drastic because of the increase in H_d in the opposite direction.

(*v*) The direct solar irradiance S acts as a better index of the attenuation processes. All the stations have their annual irradiances reduced by more than 10%. Pune and Delhi have a 16% reduction in the irradiance levels. Bhavnagar has the lowest change of 11%. Calcutta which has a consistently lower S throughout during 1985-86 receives a mere 516 Wm^{-2}, amounting to more than 30% decrease in the fifteen year periods.

(*vi*) The irradiance depends very much on the sky condition and hence on the rainfall activity also. The dust load is likely to be more in the atmosphere when there is less rainfall. In addition to the geographical feature of higher incidence of S in May, the higher values of S can also be due to measurements being taken after a wash out by thunderstorms. Even so, the overall average values show a tendency to decrease which is much more than 10% during the 15-year periods.

(*vii*) Even during years of good monsoon rains, the values of S in September and October have been showing a steady decrease over the years at almost all the stations. Pune, as a typical example, has the monthly averages in September and October :

	September	*October*
Block I	924.4 Wm^{-2}	950.1 Wm^{-2}
Block II	866.5	851.6
Block III	820.7	907.1
Block IV	—	856.7
Block V	701.6	766.2
Block VI	—	781.1

The decreasing trend is very clear.

(*viii*) The turbidity coefficient β also corroborates the variations seen in the H_d and S The change in the case of Pune is quite alarming from 0.012 in 1959-61 to 0.085 in 1985-86. Even Jodhpur, where β was 0.045 in 1970-71, shows a high value of 0.072 in 1985-86. Calcutta and for inexplicable reasons Nagpur have β consistently greater than 0.100 since 1974-76. These trends compare well with those obtained with Volz sunphotometer (Krishnanand and Maske 1983, Srivastava *et al.* 1992). Their study of turbidity parameter was though based on a different method of computation. They also find that the background turbidity is increasing steadily.

(*ix*) The net terrestrial outgoing radiant energy is found to show a steady decrease at all the locations, indicating that more and more energy is being trapped in the atmosphere and re-radiated down to the earth. This requires a much closer study than other parameters.

(*x*) The above conclusions are summarised in Table 2 as percentage variations over the period from 1970-71 to 1985-86 for the three different seasons, *viz.*, winter, pre-monsoon and post-monsoon. A reference to the seasonal rainfall data (Table 4) indicates that in majority cases almost each station excepting Pune and Bhavnagar have had rainfall much above the seasonal normal. Even the β values which show larger deviations, are of lower order when compared to winter or post-monsoon period. The surprising increase in $E_i^* \uparrow$ at Nagpur and Calcutta do require a much more stringent checking of the data being collected and the method of measurements. Table 3 gives the annual variations at all the seven stations. While the global value decreases are only marginal, decrease in S is fast and large.

References

Bach, W., 1973, "Solar irradiation and atmospheric pollution," *Arch. Met. Geophys. Bioklim.*, **ser B, 21**, p. 67-75.

Chacko, O., Desikan, V. and Iyer, N.V., 1965, "Atmospheric turbidity and aerosol content of the atmosphere over India, Proc. IQSY Symp., New Delhi, pp. 666-672.

Dogniaux, R. and Sneyers., R., 1972, On the stability of turbidity over Uccle (Belgium) during the period 1951-1970, Proc. Intl. Radiation symp. Sendai, pp. 169-172.

Fujimoto, F., 1974, "Influence of atmospheric pollution on the ground, I", *Geophys. Mag.*, **37**, 1, pp. 1-48.

Fujimoto F., 1975, Influence of atmospheric pollution on the longwave radiation, II", *Geophys. Mag.*, **37**, 3, pp. 207-256.

Junge, C., 1977, "Tropospheric Aerosols", Radiation in Atmosphere, Science Press, pp. 2-5.

Krishnanand and M-ske, S.J., 1983, "Atmospheric turbidity measurements with Volz sunphotometer at a few background air pollution monitoring network stations in India", *Mausam*, **34**, 3, pp. 327-330.

Lal, M., 1973, "Terrestrial radiation balance in the atmosphere over NW India," *Arch. Met. Geophys. Bioklim*, **ser B, 21**, pp. 233-242.

Mani, A., Chacko, O. and Iyer, N.V., 1973, "Atmospheric turbidity measurements," *Solar Energy*, **14**, pp. 185-195.

McCormick, R.A. and Baulch, D. M., 1962, "The variation with height of the dust loading over a city as determined from the atmospheric turbidity," *APCA. J.* **12**, 10, pp. 492-496.

Rangarajan, S., 1972, "Wavelength exponent for haze scattering in the tropics as determined by photoelectric photometers", *Tellus*, **2** , pp. 56-64.

Srivastava, H.N., S.V. Datar, and Mukhopadhyay, B., 1992, "Trends in atmospheric turbidity over India", *Mausam*, **43**, 2, pp. 183-190.