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Direct fluxes of illumination over India

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ABSTRACT. In the absence of direct measurements of illumination over India, an attempt has been made to compute the direct fluxes of natural illumination at ten stations in India from measurements of direct solar radiation for the whole spectrum and in well defined spectral regions and from computed values of Ångström turbidity coefficient, β and airmass, following the method indicated by Ångström and Drummond. Variations in the illumination flux during the year for different airmasses at different stations have been studied. The direct illumination flux is seen to be generally higher during winter than in the turbid summer months at all stations.

1. Introduction

In recent years, especially during and after the International Geophysical Year, there has been a large increase in the number of stations measuring solar radiation all over the world and many countries now maintain fairly extensive networks of radiation stations. This has, however, not been the case with the measurement of natural illumination, *i.e.*, the measurement of that portion of the solar energy which is visible to the human eye. Systematic measurements of daylight illumination have been attempted only at a few locations in the world. In India, although there are twenty-four stations measuring solar radiation, actual measurements of daylight illumination have been made so far only at Poona where measurements were recently started.

Measurements of natural illumination are of great importance in building engineering and architecture as well as in agricultural meteorology, where the influence of daylight on plant growth is significant. It also makes a very useful contribution to the study of the atmospheric energy balance. Systematic measurements of natural illumination have been made and the results reported by Blackwell (1953) and Worner (1957). Drummond (1956, 1958) has reported in detail the results of measurements carried out in Pretoria and Sauberer (1959) that at Vienna.

In the absence of any records of daylight illumination for India, an attempt has been made to compute the values of natural illumination of direct solar radiation from Ångström pyrheliometric measurements of direct solar radiation integrated over the whole spectrum and in well defined spectral regions using filters.

2. Method of computation

Ångström and Drummond (1962 a, 1962 b) have derived from theoretical considerations a method of computing values of direct illumination flux from measurements of direct solar radiation in the whole spectrum as well as in well defined spectral regions using Schott glass filters, OG_1, RG_2 and RG_8. From the measurements with and without filters, radiation values defined by the following integrals can be obtained:

$$\left.\begin{aligned} I_1 &= \int_0^{530} F(\lambda)\, d\lambda \\ I_2 &= \int_0^{630} F(\lambda)\, d\lambda \\ I_8 &= \int_0^{700} F(\lambda)\, d\lambda \end{aligned}\right\} \qquad (1)$$

where I_1, I_2, I_8 are the differences between the direct solar radiation intensities measured without any filters and those measured with filters OG_1, RG_2; and RG_8 respectively; $F(\lambda)$ is the intensity at wavelength λ. If the effective luminous radiation is defined by the integral:

$$\int_0^{\infty} \phi(\lambda)\ F(\lambda)\ d\lambda$$

the luminous efficiency ρ of radiation below the lower wavelength cut-off λ_m will be given by:

$$\rho = \frac{\int_0^{\infty} \phi(\lambda)\, F(\lambda)\, d\lambda}{\int_0^{\lambda m} F(\lambda)\ d\lambda} \qquad (2)$$

The function $\phi(\lambda)$ represents the relative spectral luminous responsivity of the human eye. In Eq. (2) above, $F(\lambda)$ denotes the solar radiation at a given moment with respect to its dependence on solar height, airmass and turbidity and is given by:

$$F(\lambda) = I_0(\lambda)\, \rho_{\lambda}^{\,m}\, e^{-m\,\beta\,\lambda^{-1.3}} \qquad (3)$$

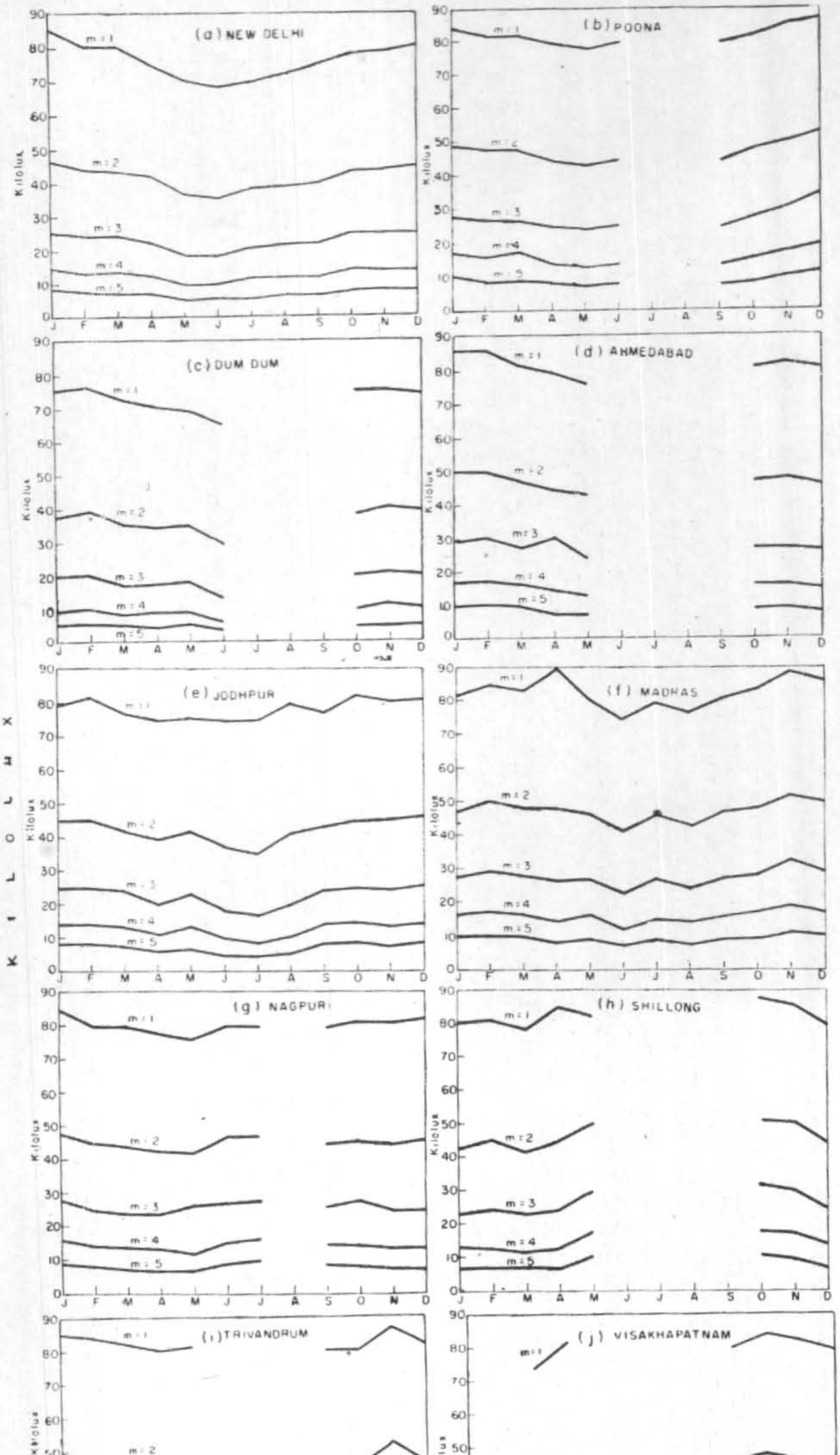

Fig. 1. Direct illumination flux for various airmasses during different months

From computations based on the above considerations it is found that the values of ρ corresponding to measurements with the filters OG_1, RG_2 and RG_8 can be expressed as simple functions of true airmass (m) and turbidity (β)

$$OG_1 : \rho = 0\cdot58(1+0\cdot235\, m+1\cdot19\, m\, \beta)$$

$$RG_2 : \rho = 0\cdot39(1+0\cdot073\, m+0\cdot305\, m\, \beta)$$

$$RG_8 : \rho = 0\cdot315\ (1+0\cdot032\, m)$$

In the above computations, values of the transmission factor ρ_λ of the Rayleigh scattering, according to Penndorf (1957) have been used and therefore, the values of β are higher than those given in Table 7 of *IGY Instruction Manual* (1958). If we multiply ρ with the energy values, W obtained by measuremenst with the different filters we obtain a measure of the direct illumination flux from Eq. (2)—

$$\rho .\, W = \int_0^\infty \phi\,(\lambda)\, F\,(\lambda)\; d\lambda \simeq E \qquad (4)$$

$$\text{where, } W = \int_0^{\lambda m} F\,(\lambda)\; d\lambda$$

If W is in cal/cm^2 min, the direct illumination flux (E) in kilolux is given by: $E = \rho .\, W .\, 475$.

3. Available data and computation

Direct solar radiation data relating to ten stations in India, *viz.*, New Delhi, Poona, Ahmadabad, Dum Dum, Jodhpur, Nagpur, Madras, Shillong, Trivandrum and Visakhapatnam were available for the computation of direct illumination flux. The direct radiation measurements were made with Ångström pyrheliometers using filters OG_1, RG_2 and RG_8 four times during the day at 0830, 1130, 1430 and 1730 IST, whenever the sun's disc and the surrounding sky were free from clouds. The number of years for which data are available for the different stations ranges from about 2-12 years, with 12 years' data for Poona and New Delhi and about 2-4 years' data for the remaining stations. Values of luminous efficiency and the direct fluxes of illumination were calculated individually for all the available observations and for measurements with the three filters, OG_1, RG_2 and RG_8. The values of illumination corresponding to a particular observation of direct solar radiation were comparable though not identical when computed separately on the basis of measurements with OG_1, RG_2 and RG_8. The illumination values were then plotted against airmass for each month and for each time of observation for the different stations. The values of illumination flux for fixed airmasses were picked out from the graph. From these the values of the mean illumination flux at fixed airmasses ranging from 1-5 for the different months were determined and are given in Fig. 1(a-j). Maps showing the distribution of illumination over India for the months January, April, July and October are given in Fig. 2 (a-d).

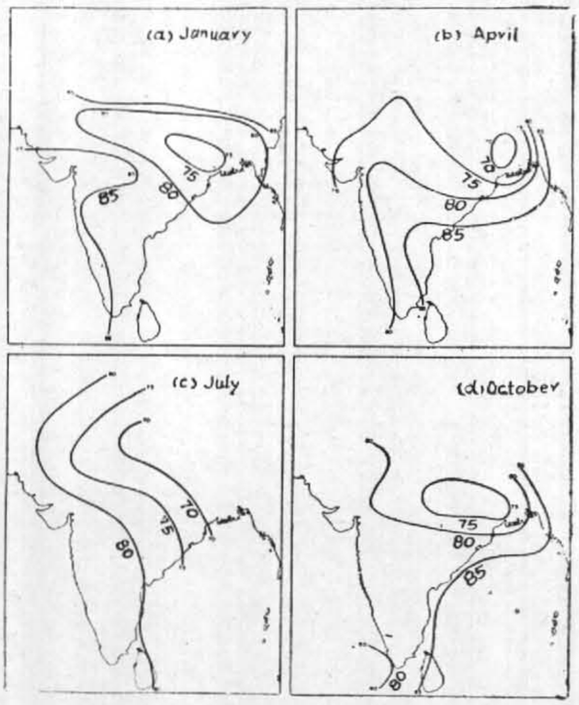

Fig. 2

Direct illumination flux (kilolux)) for unit airmass

4. Discussion of results

It will be seen from Fig. 1(a-j) that the direct natural illumination flux normal to the solar beam lies within the range 65 90 kilolux for unit airmass for the 10 Indian stations with average and annual values of about 79 kilolux for the northern stations and about 83 kilolux for the southern stations. There is generally a decrease in illumination at all stations during the turbid summer months and an increase during winter. This is particularly marked at New Delhi where the illumination flux changes from 68 kilolux in June to 85 kilolux in January. This is less marked but still significant at Madras, Nagpur, Ahmadabad and Dum Dum and less marked at the remaining stations. At Dum Dum the illumination flux is the lowest throughout the year with a mean value of 72 kilolux, whereas it is uniformly high throughout the year at Poona, Shillong, Vizag and Trivandrum, the mean value being of the order of 83 kilolux. The highest values are recorded at

Madras with the illumination flux reaching a maximum of 90 kilolux in April.

The seasonsal variations are associated with the variations in the transparency of the sky during different months. During the winter months in the north Indian stations where temperature inversion forms at low levels permitting the accumulation of pollutants in the lower layers of the atmosphere, the illumination flux values are lower than at stations in the south like, Madras and Trivandrum or Poona and Shillong at higher altitudes where higher values are reached. During the dry turbid summer months, the illumination flux is uniformly low at all stations particularly in Calcutta where industrial pollution is responsible for the very low values obtained. Except for Calcutta, where the natural illumination is lower than that at all other stations throughout the year, the values are uniformly high in January and least in April and July.

5. Conclusion

In the absence of direct measurements of natural illumination and in view of the uncertainties in the sensitivity of photoelectric cells normally used for direct measurements, the techuique of computing direct illumination flux from radiometric measurements will be seen to be of great importance. A general study of natural illumination flux values computed for 10 Indian stations shows that the average value for India is of the order of 80 kilolux with high values in winter and low values in the premonsoon summer months. Calcutta with its high industrial pollution has the lowest values recorded, 65-80 kilolux. The computed values of direct illumination flux for the stations in India are also slightly less than those reported by Drummond (1956) for Pretoria and this is presumably due to the higher turbidity at the Indian stations.

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