The transparency of the atmosphere over India

N. V. IYER
Meteorological Office, Pune
(Received 18 January 1985)

ABSTRACT. The transparency of the atmosphere (q) over India has been studied from global (G) and diffuse solar radiation (D) measurements in India. The ratio \( D/G \) and \( D/(G-D) \) which indicate the scattering have also been studied for all the stations.

1. Introduction

A systematic study of the transparency of the atmosphere to solar radiation (q) from the global (G) and diffuse (D) radiation measurements in India has been made. The variation of 'q' with respect to time and season for all the stations in India have been presented. The scattering generally represented by the ratio \( D/G \) and their variation with time and season have also been discussed. Since \( D \) is a part of \( G \), it is felt that the ratio \( D/G-D \) may represent the scattering better. Therefore, these ratios also have been included in the study.

Further, variation in the general depletion of radiation is due to the prevalence of aerosol, water vapour and other pollutants in the atmosphere. Therefore, the increase in these, will naturally result in a decrease in incoming solar radiation and so the transparency. The ratio \( D/G \) and \( D/(G-D) \) will then increase. The values could thus be useful in the study of air pollution as a qualitative estimation of the variation of atmospheric particles comprising of aerosols, pollutants etc. The study of pollution is of late gaining significant importance.

2. Data

The individual measurements of the intensity of solar radiation would have been more accurate for the purpose. Only spot readings of this parameter are possible either near about fixed hours or constant atmospheric depths. Hence, the global and diffuse solar radiation data obtained from continuous records have been used for the present study. The departmental publication 'Radiation short period averages' based on data from 1957 to 1975, contain global and diffuse radiation data on cloudless days. Moreover, since clouds absorb, reflect and scatter radiation energy received, the variation of the depletion of solar radiation in the atmosphere is very wide in the presence of clouds. Hence the data on cloudy days is not suitable for the work.

3. Computation

It is very well known that

\[ G - D = I \sin h, \]

where, 'G' is global solar radiation

'D' is diffuse solar radiation

'G-D' represents the component of radiation from the sun received on a horizontal surface on the earth.

'I' is the intensity of solar radiation received at earth on a surface placed perpendicular to the sun's rays.

'h' is the solar elevation, which is determined by the formula \( \sin h = \sin \delta + \cos \phi \cos \delta \cos t \) where, '\( \delta \)' is the latitude of the place, '\( \phi \)' is the declination of the sun and 't' is the hour angle.

As per the formula by Bouguer

\[ I = I_0 q^m \]

where \( I_0 \) is the extraterrestrial intensity of solar radiation, 'q' is the transmission coefficient and 'm' the airmass. This law is valid strictly only for monochromatic radiation. This is, however, used as an approximate extension.

The solar constant has been taken as 1.98 cal/cm²/min. This has been corrected for sun earth distance to determine \( I_0 \). 'm' is the airmass or the thickness of the atmosphere when compared to that of an overhead sun, and is greater than one, for a station at sea level.
Fig. 1
TABLE I
Maximum and minimum q, D/G and D/G—D (Percentage)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Station</th>
<th>Lat. (Deg. Min. Decl.)</th>
<th>Long. (Deg. Min. Decl.)</th>
<th>Eleva. (m)</th>
<th>Max q % Month</th>
<th>Min q % Month</th>
<th>Max-Min</th>
<th>Max D/G % Month</th>
<th>Min D/G % Month</th>
<th>Max D/G—D % Month</th>
<th>Min D/G—D % Month</th>
<th>Max D/G—D % Month</th>
<th>Min D/G—D % Month</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>New Delhi</td>
<td>28° 35’ 77° 12’</td>
<td>216’</td>
<td>77 Dec</td>
<td>51 Jun</td>
<td>26</td>
<td>25 Aug</td>
<td>17 Jan</td>
<td>8</td>
<td>55 Aug</td>
<td>17 Jan</td>
<td>8</td>
<td>17 Jan</td>
</tr>
<tr>
<td>2</td>
<td>Jodhpur</td>
<td>26° 18’ 73° 01’</td>
<td>224’</td>
<td>79 Dec</td>
<td>49 Jun</td>
<td>30</td>
<td>25 Jun</td>
<td>13 Nov</td>
<td>12</td>
<td>33 Jun</td>
<td>15 Nov</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Shillong</td>
<td>25° 34’ 91° 53’</td>
<td>1600’</td>
<td>83 Jan</td>
<td>57 May</td>
<td>26</td>
<td>21 May</td>
<td>7 Jan</td>
<td>14</td>
<td>25 May</td>
<td>8</td>
<td>17 Nov</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>Ahmedabad</td>
<td>23° 04’ 72° 38’</td>
<td>55’</td>
<td>75 Dec</td>
<td>55 Jun</td>
<td>20</td>
<td>20 Jun</td>
<td>14 Nov</td>
<td>6</td>
<td>25 Jun</td>
<td>17 Nov</td>
<td>8</td>
<td>17 Nov</td>
</tr>
<tr>
<td>5</td>
<td>Calcutta</td>
<td>22° 32’ 88° 20’</td>
<td>6’</td>
<td>70 Jan</td>
<td>47 May</td>
<td>23</td>
<td>30 May</td>
<td>20 Oct/Nov/Dec</td>
<td>10</td>
<td>43 May</td>
<td>24 Nov</td>
<td>19</td>
<td>24 Nov</td>
</tr>
<tr>
<td>6</td>
<td>Bhavnagar</td>
<td>21° 45’ 72° 11’</td>
<td>5’</td>
<td>75 Dec</td>
<td>54 Jun</td>
<td>21</td>
<td>21 May</td>
<td>14 Dec</td>
<td>7</td>
<td>27 May</td>
<td>17 Dec</td>
<td>10</td>
<td>17 Dec</td>
</tr>
<tr>
<td>7</td>
<td>Nagpur</td>
<td>21° 06’ 79° 03’</td>
<td>310’</td>
<td>74 Dec</td>
<td>52 Jun</td>
<td>22</td>
<td>22 Jun</td>
<td>14 Dec</td>
<td>8</td>
<td>29 May/June</td>
<td>16 Dec</td>
<td>13</td>
<td>16 Dec</td>
</tr>
<tr>
<td>8</td>
<td>Bombay</td>
<td>19° 07’ 72° 51’</td>
<td>14’</td>
<td>71 Dec</td>
<td>47 May</td>
<td>24</td>
<td>31 Apr</td>
<td>17 Nov</td>
<td>8</td>
<td>45 May</td>
<td>15 Nov</td>
<td>30</td>
<td>15 Nov</td>
</tr>
<tr>
<td>9</td>
<td>Poona</td>
<td>18° 32’ 73° 51’</td>
<td>559’</td>
<td>75 Dec</td>
<td>57 Jun</td>
<td>18</td>
<td>18 Jun</td>
<td>12 Dec</td>
<td>6</td>
<td>23 Jun</td>
<td>14 Dec</td>
<td>9</td>
<td>14 Dec</td>
</tr>
<tr>
<td>10</td>
<td>Visakhapatnam</td>
<td>17° 43’ 83° 14’</td>
<td>3’</td>
<td>72 Dec</td>
<td>49 May</td>
<td>23</td>
<td>26 May</td>
<td>13 Nov</td>
<td>13</td>
<td>35 May</td>
<td>15 Nov</td>
<td>20</td>
<td>15 Nov</td>
</tr>
<tr>
<td>11</td>
<td>Goa</td>
<td>15° 29’ 73° 49’</td>
<td>55’</td>
<td>77 Dec</td>
<td>58 May</td>
<td>19</td>
<td>19 Apr/ May</td>
<td>13 Dec</td>
<td>6</td>
<td>23 Apr/ May</td>
<td>14 Dec</td>
<td>9</td>
<td>14 Dec</td>
</tr>
<tr>
<td>12</td>
<td>Madras</td>
<td>13° 00’ 80° 11’</td>
<td>16’</td>
<td>77 Dec</td>
<td>51 Jun</td>
<td>26</td>
<td>23 Jun</td>
<td>11 Dec</td>
<td>12</td>
<td>29 Jun</td>
<td>13 Dec</td>
<td>16</td>
<td>13 Dec</td>
</tr>
<tr>
<td>13</td>
<td>Trivandrum</td>
<td>8° 29’ 76° 57’</td>
<td>64’</td>
<td>69 Dec/Jan</td>
<td>55 Apr</td>
<td>14</td>
<td>22 Apr</td>
<td>14 Dec</td>
<td>8</td>
<td>28 Apr</td>
<td>17 Dec</td>
<td>11</td>
<td>17 Dec</td>
</tr>
</tbody>
</table>

\[ m_{\text{adj}} = \frac{1}{\sin h} \] for \( h \) greater than 20°.

Since the average monthly means have been utilised, ‘\( \sin h \)' has been calculated for the middle day of the month, every mid-hour local apparent time or true solar time. As the radiation values are very small, the results of computations are not reliable for very low solar elevations. Such values have been omitted.

4. Observations

Isolines depicting the variations of \( q, D/G \) and \( D/G—D \) with time and season for the thirteen stations, viz., New Delhi, Jodhpur, Shillong, Ahmedabad, Calcutta, Bhavnagar, Nagpur, Bombay, Poona, Visakhapatnam, Goa, Madras and Trivandrum are given in the Figs. 1-4. Given below are a few general observations:

(i) ‘\( q \)' of the atmosphere is higher in the morning, decreases towards noon and increases again in the afternoon. This could be due to increasing convectivity towards noon.

(ii) ‘\( q \)' is high in clear winter season but decreases towards summer as the aerosol or dust content of the atmosphere increases. After the rainy season, due to the washout by rain, the transparency increases again.

(iii) The ratio \( D/G \) and \( D/G—D \) also decreases from morning to noon and increases towards the evening. This is so because of the lower and lower depth of the atmosphere through which the sun’s rays have to pass through or airmass ‘‘m’’ as the sun is more and more near the zenith.

(iv) The seasonal variation of these ratios show a similar but opposite trend to that of ‘‘q’’ with the minimum generally in November. In December ‘‘m’’ in high, more so for the northern stations, as the sun is farthest to the south.

The details of the stations, the maximum and minimum values, and their variations are presented in Table 1.

The Indian atmosphere is most transparent in December/January, the clear winter. The highest value of 83% is at Shillong in January. This is a hill station, generally characterised by a clear atmosphere. Also the airmass ‘‘m’’ is least. Most of the north Indian stations are having a transparency of about 75% this time, probably because of moisture and winds caused by northeast monsoon bringing in aerosol. The next lowest is Calcutta which is well known to be a highly industrialised and polluted city.
The least transparency of the Indian atmosphere occur mostly in May/June just before the onset of monsoon as the aerosol content is very high whereas it occurs in April in Trivandrum, probably due to the summer convective activity which is maximum this time at the station. The lowest value of 47% occurs in the well polluted cities Bombay and Calcutta in May. Next value of 49% at Visakhapatnam could be due to high pollution. 51% is the transparency at New Delhi because of its dusty atmosphere due to its proximity to the semi-arid region.

The variation of ‘a’ is high, 30% at Jodhpur, which is in the semi-arid zone. In highly polluted cities the variations are low, viz., 18% in Poona, 20% in Ahmedabad and 23% at Calcutta. The least variation of 14% is at Trivandrum, where the seasonal variation of temperature and moisture is the least. This station experiences the strong winds of both southwest and northeast monsoons.

The values of D/G and D/G−D represent the scattering. Naturally, D/G−D is higher than the ratio D/G. Due weightage has to be given to the airmass while discussing these ratios. The highest value is at the polluted Calcutta, followed by Visakhapatnam and the semi-arid Jodhpur and the proximate New Delhi, mostly in May/June. It is in August at Delhi because the monsoon sets is later than other parts of the country and the rainfall is not much.

These ratios are the least generally in winter months. The least value of 7% is in Shillong, the hill station
characterised by the clear and thin atmosphere. The low values of $D/G$ and $D/G-D$ are more or less same in Shillong.

The variation between maximum and minimum values of $D/G$ is generally low at coastal stations.

A discussion on the relative variations on $q$ and turbidity coefficient $\beta$ is not being attempted since this has been dealt for a few stations in some of the papers under reference, especially on Jodhpur.

Acknowledgement

The author is grateful to Shri M.R. Das, Meteorologist for very useful suggestions and Shri O. Abraham for getting computations done writing a suitable program.

References

Chacko, O., Desikan, V. and Iyer, N.V., [1967, 'Atmospheric turbidity and aerosol content of the atmosphere over India,' IQSY Symposium, NPL, New Delhi, pp. 666-672.


Fig. 4


Rao, K.N. and Ganesan, H.R., 1972, 'Global Solar and diffuse solar sky radiation over India', IMD. Met. Monogr; Climatology/No. 2.