Abstract

Mean radius ($\bar{r}$) and moments around $\bar{r}$, total concentration of droplets, liquid water content ($W$), terminal fall speed and visual range ($V_m$), have been computed for a sample of 239 droplet size distributions of valley, advection and radiation fog. The scattering, absorption and extinction coefficients, the albedo for single scattering, the phase function $P(\cos \theta)$ at several scattering angles $\theta$, the coefficients $x_n$, $x_m$ connected with the Legendre series expansion and the $b$-$M$ approximation of the phase function have also been computed at seventy-four wavelengths from 0.35 to 90 $\mu$m.

Data elaboration has basically consisted in the determination of the standard statistical parameters (histogram, mean, value, dispersion, skewness and kurtosis) for each of the above quantities and each of the various fog groups considered.

Results concerning the grouping of fog spectra according to the fog type show that all the quantities are widely dispersed within each fog group and, in addition, the respective histograms partially overlap to each other; similar results also emerge by grouping the spectra according to their values of $W$ and $V_m$, so that it appears unreliable to consider mean values as characteristic of a given fog group. Finally, a description of the mean physical and optical properties of the whole sample is presented, with the spectra all grouped together.
fifth and third moment of the size distribution at hand, and $k_a = 1.202 \cdot 10^{-2} \text{cm} \cdot \text{s}^{-1} \cdot \mu \text{m}^{-2}$.

As to the optical properties, the volume scattering, absorption and extinction coefficients $\sigma_s, \sigma_a, \sigma_e \quad (\text{m}^{-1})$ associated to fog droplets, together with the phase function $P(\cos \theta)$, where $\theta$ is the scattering angle, completely define the optical properties of a fog in the absence of polarization effects.

When radiative transfer computations (Lenoble, 1977) are involved, the attenuation properties of fog are expressed through the albedo for single scattering $\omega = \sigma_s / \sigma_e$ and the optical depth $\tau = \int_0^z \sigma_e \, dz$, where $z$ is the vertical coordinate and $z_1$ is its value at the fog upper boundary. To the same end, $P(\cos \theta)$ is expanded in an $N$-term series of Legendre polynomials $P_n(\cos \theta)$,

$$P(\cos \theta) = \sum_{n=0}^{N} (2n+1) \cdot \chi_n \cdot P_n(\cos \theta), \quad (1)$$

where the $\chi_n$ are the moments of $P(\cos \theta)$ with respect to $P_n(\cos \theta)$, given by

$$\chi_n = \frac{1}{2} \int_0^\pi P(\cos \theta) \cdot P_n(\cos \theta) \cdot \sin \theta \cdot d\theta, \quad (2)$$

with $\chi_0 = 1.0$.

A very useful approximation to $P(\cos \theta)$ is the $\delta-M$ approximation (Wiscombe, 1977), which separates the contribution of the forward peak from that of the remaining angles and expresses the forward peak as a $\delta$-function, namely

$$P_{\delta-M}(\cos \theta) = 2f \cdot \delta(1-\cos \theta) + (1-f) \sum_{m=0}^{2M} (2m+1) \cdot \chi_m \cdot P_m(\cos \theta); \quad (3)$$

$M = 1, 2, \ldots$ is the order of the approximation, $f$ and the $\chi_m^*$ are given as a function of the $\chi_n$ by

$$\chi_m^* = \frac{\chi_m - \chi_{2M}}{1 - \chi_{2M}}$$

$$f = \chi_{2M}, \quad (m = 0, \ldots, 2M - 1). \quad (4)$$

From (4) it follows $\chi_0^* = 1.0$.

$P(\cos \theta)$ in (1) has to be understood as integrated over $r$ via the droplet radius distribution function $f(r)$, according to

$$P(\cos \theta) = \frac{1}{2\pi\sigma_a} \int_{r_m}^{r_M} [i_1(r, \theta, \tilde{m}) + i_2(r, \theta, \tilde{m})] \cdot f(r) \cdot dr, \quad (5)$$

where $r_m$ and $r_M$ are the lower and upper radius of the size distribution at hand, $i_1(r, \theta, \tilde{m})$ and $i_2(r, \theta, \tilde{m})$ the Mie intensity functions and $\tilde{m}$ the complex refractive index.

For each size distribution the quantities $\sigma_s, \sigma_a, \sigma_e, \omega, P(\cos \theta)$ at several $\theta$ (a maximum of 180 values at the shortest wavelengths), $\chi_n$ for $n = 0, \ldots, 15$ and $\chi_m^*$ for $M = 1, \ldots, 5$, have been computed at 74 wavelengths from 0.35 to 90 $\mu$m. The meteorological visual range $V_m$ (m), defined as $V_m = 3.912/\sigma_e (0.55 \mu m)$, has been also computed.

Spectra have been grouped according to three different criteria, and for each group and each of the above quantities the normalized histogram, the mean value, the coefficient of dispersion (standard deviation over mean value, in percent), the skewness and the kurtosis (third and fourth dimensionless moments around the mean) have been determined. In addition, for each quantity, the overlapping area of two by two histograms, as well as that of all taken together, has been determined; it gives the percentage of values shared by the histograms belonging to the fog groups considered.

Not all the computed data have been shown in the present paper; further results can be found in a Report (Tonna, 1989) which can be obtained on request from the author.

3. Results

a. Spectra grouped according to the fog type

In this case spectra have been grouped in valley, advection and radiation fog groups, in accordance with the attributions given by the authors in their papers. Results concerning shape and mass properties are given in Table 1, and those concerning optical properties in Tables 2-3 and in Fig.1; in Sects. 3a and 3b optical properties are considered at $\lambda = 0.55, 1, 2, 10$ and 25$\mu$m.

The quantities $r, \sigma, \sigma_a$ and $\sigma_3$, which characterize the shape of a spectrum, show (Table 1) large values of both the dispersion coefficients (disp) and the overlapping area (int). For instance, for the mean radius $r$ disp is 15, 38 and 39% for the valley, advection and radiation fog groups, and int is 31, 69, 80 and 25% for the overlap of the histograms of the valley-advection, valley-radiation, advection-radiation and valley-advection-radiation fog groups, respectively. These values are even greater for the other shape parameters $\sigma, a_3$ and $a_4$.

These findings confirm the high variability of the shape of the fog spectra and show that it is unreliable to define typical or characteristic spectra for each fog type if we assume disp = 10% and int = 5% as reasonable values. Of course, it can be useful to have reference spectra through which to set up computational procedures or to compare results of different authors and in this vein can be used, for instance, the spectra given by Tampieri and Tomasi (1976) and those by Deirmendjian (1969).

Table 1 also contains data on the mass quantities
Table 1. Mean values, dispersion coefficients and overlapping area of the histograms, for the quantities listed on the 1st column. Spectra have been grouped according to the fog type. The 1st, 2nd and 3rd columns, for the mean and disp (%) headings, refer to valley, advection and radiation fog, respectively. For the int (%) heading, the 1st, 2nd, 3rd and 4th columns refer to the overlap of the histograms of the valley-advection, valley-radiation, advection-radiation and valley-advection-radiation fog groups, respectively. The number of spectra in each group is 32, 119 and 88, respectively.

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>disp(%)</th>
<th>int(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{r}(\mu m)$</td>
<td>9.07</td>
<td>7.29</td>
<td>6.02</td>
</tr>
<tr>
<td>$\sigma(\mu m)$</td>
<td>4.36</td>
<td>3.45</td>
<td>2.14</td>
</tr>
<tr>
<td>$a_3$</td>
<td>0.81</td>
<td>1.62</td>
<td>1.81</td>
</tr>
<tr>
<td>$a_4$</td>
<td>3.78</td>
<td>12</td>
<td>54</td>
</tr>
<tr>
<td>$N (cm^{-3})$</td>
<td>25</td>
<td>93</td>
<td>682</td>
</tr>
<tr>
<td>$W (g \cdot m^{-3})$</td>
<td>0.134</td>
<td>0.121</td>
<td>0.139</td>
</tr>
<tr>
<td>$v (cm \cdot s^{-1})$</td>
<td>3.09</td>
<td>2.71</td>
<td>1.21</td>
</tr>
<tr>
<td>$V_m (m)$</td>
<td>371</td>
<td>711</td>
<td>210</td>
</tr>
</tbody>
</table>

Table 2. Dispersion coefficients and overlapping area of the histograms, for $\sigma_s$, $\sigma_a$, $\sigma_e$ and $\bar{w}$ at $\lambda = 0.55$, 2 and 10 $\mu m$. Spectra have been grouped according to the fog type. For the disp and int headings, see Table 1. At $\lambda = 0.55 \mu m$, $\sigma_a = 0.0$ and $\bar{w} = 1.0$.

<table>
<thead>
<tr>
<th></th>
<th>0.55 $\mu m$</th>
<th>int</th>
<th>2 $\mu m$</th>
<th>disp</th>
<th>int</th>
<th>10 $\mu m$</th>
<th>disp</th>
<th>int</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_s$</td>
<td>45</td>
<td>74</td>
<td>60</td>
<td>46</td>
<td>29</td>
<td>35</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>42</td>
<td>69</td>
<td>70</td>
<td>64</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>43</td>
</tr>
<tr>
<td>$\sigma_e$</td>
<td>45</td>
<td>74</td>
<td>60</td>
<td>46</td>
<td>29</td>
<td>35</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>$\bar{w}$</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>17</td>
<td>6</td>
<td>30</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3. Disp and int for the $\chi_a$. Spectra have been grouped according to the fog type.

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>0.55 $\mu m$</th>
<th>int</th>
<th>2 $\mu m$</th>
<th>disp</th>
<th>int</th>
<th>10 $\mu m$</th>
<th>disp</th>
<th>int</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi_1$</td>
<td>0.2</td>
<td>1</td>
<td>2</td>
<td>37</td>
<td>73</td>
<td>58</td>
<td>26</td>
<td>0.6</td>
</tr>
<tr>
<td>$\chi_2$</td>
<td>0.3</td>
<td>1</td>
<td>3</td>
<td>38</td>
<td>75</td>
<td>62</td>
<td>29</td>
<td>0.8</td>
</tr>
<tr>
<td>$\chi_3$</td>
<td>0.4</td>
<td>2</td>
<td>4</td>
<td>38</td>
<td>72</td>
<td>71</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>$\chi_4$</td>
<td>0.4</td>
<td>2</td>
<td>5</td>
<td>37</td>
<td>50</td>
<td>82</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>$\chi_5$</td>
<td>0.4</td>
<td>3</td>
<td>7</td>
<td>33</td>
<td>7</td>
<td>30</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>$\chi_6$</td>
<td>0.4</td>
<td>3</td>
<td>9</td>
<td>31</td>
<td>2</td>
<td>19</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>$\chi_7$</td>
<td>0.5</td>
<td>3</td>
<td>10</td>
<td>32</td>
<td>0</td>
<td>17</td>
<td>0.3</td>
<td>2</td>
</tr>
<tr>
<td>$\chi_8$</td>
<td>0.6</td>
<td>4</td>
<td>12</td>
<td>24</td>
<td>0</td>
<td>14</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>$\chi_9$</td>
<td>0.6</td>
<td>4</td>
<td>13</td>
<td>30</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>$\chi_{10}$</td>
<td>0.7</td>
<td>4</td>
<td>15</td>
<td>27</td>
<td>0</td>
<td>14</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>$\chi_{11}$</td>
<td>0.7</td>
<td>5</td>
<td>16</td>
<td>28</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>$\chi_{12}$</td>
<td>0.8</td>
<td>5</td>
<td>17</td>
<td>27</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>$\chi_{13}$</td>
<td>0.8</td>
<td>5</td>
<td>17</td>
<td>27</td>
<td>0</td>
<td>18</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>$\chi_{14}$</td>
<td>0.9</td>
<td>6</td>
<td>18</td>
<td>27</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>$\chi_{15}$</td>
<td>0.9</td>
<td>6</td>
<td>19</td>
<td>26</td>
<td>0</td>
<td>19</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

$N, W, v$ and on the visual range $V_m$, whose values of disp and int greatly exceed the reference values. $\lambda = 0.55, 2$ and $10 \mu m$, are given. The values of disp and int are generally greater than the assumed reference values (disp 10\%, int 5\%). At visible
wavelengths $\sigma = 0.00000$, so that $\theta = 1.0000$ with disp=0.00\%. Values at $\lambda = 1\mu m$ are between those at $\lambda = 0.55$ and $2\mu m$, while values at $25\mu m$ are quite similar to those at $\lambda = 10\mu m$, so that they have been omitted.

Results concerning $P(\cos \theta)$ for $\lambda = 1\mu m$, are given in Fig. 1, where disp and int, as a function of $\theta$ are reported; for graphical reasons abscissae are unequally spaced. The net of curves at the other $\lambda$ is similar, possibly with greater values of disp and int; at the shortest $\lambda$ some $\theta$-interval with disp < 10\% or int < 5\% can be found, but the two situations never occur simultaneously.

Results concerning $\chi_m$ are connected to those for $P(\cos \theta)$, but they are presented separately in Table 3. Here, too, we generally find values of disp and int exceeding the reference values.

From the above data we conclude that it is unreliable to define typical quantities for each fog type because of the high values of the dispersion coefficients and, more significantly, because the different fog types exhibit similar values of the quantities considered, as shown by the high values of the intersection area of the histograms.

Of course, we can find wavelengths were some parameter is better characterized, e.g., $\omega$, $\chi_m$ and $x_m^*$ at $\lambda = 0.55\mu m$. As to $\omega$, we believe it is of some interest that at visible wavelengths its value comes out to be rigorously unity and we shall come back to this point in Sect. 3c. As to $\chi_m$, the values of disp are rather small but we have to take into account that each $\chi_m$ differs from the proceeding one by less than disp, so that these rather small values don’t allow us to distinguish between one $\chi_m$ and the next closest one and thus to determine the whole set of the $\chi_m$; besides, the relevant values of int almost always exceed the reference value. As to $\chi_m^*$, the relative differences between contiguous $\chi_m^*$ are much greater than disp, but again we have large values for the overlapping area. Finally, as the above considered parameters are used as input data to radiative transfer models, we have to take into account (Ronnholm et al., 1980; Wiscombe, 1977) that variations of 1\% in these parameters entail variations of 10\% and more in transmissions and fluxes. The variations are even greater when flux divergences are computed.

b. Spectra grouped according to $W$ and $V_m$

A better criterion for finding some regularity could be to classify the spectra according to their evolutionary stage defined through labels like ‘formation stage’ or ‘mature stage’ (Tampieri and
Table 4. Mean values, dispersion coefficients, skewness and kurtosis, for the quantities listed on the 1st and 4th column. Spectra have been grouped all together. $a_3$ and $a_4$ on the line refer to the shape of the droplet size distributions.

<table>
<thead>
<tr>
<th>$\bar{r} (\mu m)$</th>
<th>mean</th>
<th>disp(%)</th>
<th>$a_3$</th>
<th>$a_4$</th>
<th>$N (cm^{-3})$</th>
<th>mean</th>
<th>disp(%)</th>
<th>$a_3$</th>
<th>$a_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.06</td>
<td>38</td>
<td>0.11</td>
<td>3.6</td>
<td></td>
<td>301</td>
<td>421</td>
<td>5.7</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>3.10</td>
<td>41</td>
<td>0.38</td>
<td>3.1</td>
<td></td>
<td>0.129</td>
<td>67</td>
<td>1.3</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>1.58</td>
<td>207</td>
<td>6.1</td>
<td>45</td>
<td></td>
<td>2.21</td>
<td>73</td>
<td>1.9</td>
<td>7.4</td>
<td></td>
</tr>
<tr>
<td>26.4</td>
<td>640</td>
<td>11</td>
<td>129</td>
<td></td>
<td>482</td>
<td>369</td>
<td>13</td>
<td>189</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. Behavior of the average attenuation coefficients with wavelength.

Tomasi, 1976), or to use the time, starting from fog formation. The first criterion is empirical because evolutionary stages are not defined through some measurable parameter, while there is not a unique time variable for all the fog events. In order to classify spectra according to a measurable parameter connected with the evolution of a fog, we have used both liquid water content and visual range. Of course, $W$ and $V_m$ depend in their turn on the size spectra, but $W$ is easily generated, in fog models, independently of the size spectrum, while $V_m$ correlates rather well with $W$ (corr. coeff. = 0.82, according to Tonna and Valenti, 1986). Furthermore both $W$ and $V_m$ can easily be measured in field experiments.

Spectra have been grouped according to $W$ (and to $V_m$) by dividing the range of the $W(V_m)$ values into three intervals. The intervals for $W$ are $0 \leq W \leq 0.08$, $0.08 < W < 0.16$ and $W \geq 0.16$ g.m$^{-3}$; the number of spectra in each group is 79, 90 and 70, respectively. The intervals for $V_m$ are $0 \leq V_m < 120$, $120 < V_m < 280$ and $V_m \geq 280$ m; the spectra in each group are 68.99 and 72, respectively.

The results show the same features as those of Sect. 2a, so that $W$ and $V_m$ turn out not to be good parameters for classifying fog properties. As numerical relevant data have been omitted, we summarize this attempt as follows.

The grouping according to $W$, when compared with the data of Sect. 2a, leads to the following results: 1) as to shape and mass parameters, no substantial improvement, except for $W$ which actually classifies itself; 2) as to $\sigma_z$, $\sigma_a$, $\sigma_e$ and $\tilde{\omega}$, only a slight improvement; 3) as to $P(\cos \theta)$, disp vs. $\theta$ behaves similarly to the curves of Fig. 1 at the same $\lambda$ while the four values of int are rather steady and centered around the indicative values 71, 58, 66 and 52; 4) $\chi_n$ and $\chi^*_m$ behave distinctly worse.

The grouping according to $V_m$ leads to the following results: 1) as to shape and mass parameters, no substantial improvement, except for $V_m$ which actually classifies itself; 2) slight improvement for $\sigma_z$, $\sigma_a$, $\sigma_e$ and $\tilde{\omega}$, mainly at the short $\lambda$ where $\sigma_z \simeq \sigma_e$, due to fact that, from the definition of $V_m$, $\sigma_z$ classifies itself; 3) for $P(\cos \theta)$ see the above point 3); 4) $\chi_m$ and $\chi^*_m$ behave distinctly worse.

The $W$- and $V_m$-intervals have also been made narrower and their number has been increased, but the general result was still of the same kind.

c. All the spectra together

Results concerning all the spectra together are given in Table 4 and in Figs. 2 to 6.
Fig. 3. Behavior of the average albedo for single scattering, and of the corresponding dispersion coefficients, skewness and kurtosis, with wavelength.

Fig. 4. Magnification of Fig. 3, in the 0.35-15 \(\mu m\) wavelength range.

Fig. 5. Behavior of the coefficient \(f \equiv \chi^2\) of Eq. (6), vs. \(\lambda\).

In Table 4 we have data concerning shape and mass properties. Dispersions are of the same order of magnitude as those of Table 1; as to \(a_3\) and \(a_4\), they indicate that, i.e., \(F\) is almost normally distributed (\(a_3 = 0\), \(a_4 = 3\), for a normal distribution) while \(V_m\) is skewed to the right (\(a_3 > 0\)) and much more peaked than a normal distribution (\(a_4 \gg 3\)).

Fig. 2 shows the behavior of \(\sigma_s\), \(\sigma_a\) and \(\sigma_e\) with \(\lambda\). We note the following features: 1) \(\sigma_s\) has well pronounced minima at \(\lambda = 3, 4.6, 6\) and 11.5 \(\mu m\), maxima at 3.8, 5.4 \(\mu m\), and it varies within a factor of 4; 2) \(\sigma_a\) has minima at \(\lambda = 1.6, 2.2, 3.8, 5.3\) \(\mu m\), maxima at 1.4, 2, 3, 4.7, 6 \(\mu m\), and it varies over more than two orders of magnitude; 3) \(\sigma_e\) has minima at \(\lambda = 6.05\) and 10.2 \(\mu m\), while over the whole range it varies within a factor of 1.7. As to the relative contribution of \(\sigma_s\) and \(\sigma_a\) to \(\sigma_e\), we have \(\sigma_s > \sigma_a\) for \(\lambda < 10.8\) \(\mu m\) and \(\sigma_a > \sigma_s\) for \(\lambda > 10.8\) \(\mu m\); at visible wavelengths \(\sigma_e \cong \sigma_s\). The relevant behavior of disp, \(a_3\) and \(a_4\) have been omitted since they are almost constant with \(\lambda\) and their indicative values are 70, 1, 4 for \(\sigma_s\), 68, 1, 4 for \(\sigma_a\) and 69, 1, 4 for \(\sigma_e\), so that the histograms of the attenuation coefficients come out to be skewed to the right and more peaked than
According to Eq. (4) it is given by
\[ g' = \frac{x^2 - 1}{1 - x^2}, \]
where \( g \equiv \chi_1 \) is the asymmetry factor of the actual phase function.

The behavior of the optical quantities presents marked variations for \( \lambda < 10 \) \( \mu m \), while for \( \lambda > 10 \) \( \mu m \) it is very smooth. This feature is due to the behavior of the imaginary part of the complex refractive index in the \( \lambda = 0.35 - 7 \) \( \mu m \) interval. While the real part is almost a constant over the considered \( \lambda \)-range, the imaginary coefficient \( k \) varies over more than eight orders of magnitude, with well pronounced maxima and minima at \( \lambda = 0.5, 1.4, 1.6, 2.0, 2.2, 3.0, 3.8, 4.7, 5.3 \) and \( 6.05 \) \( \mu m \) (Hale and Querry, 1973). These peaks in the behavior of \( k \) induce corresponding peaks in the behavior of \( \sigma_s, \sigma_a, \sigma_e, \bar{\omega}, f \) and \( g' \) as well as of disp, \( a_3 \) and \( a_4 \).

The above findings are in agreement with previously published computations and measurements by: (1) Zdunkowski and Strand (1969), who computed \( \sigma_s, \sigma_a \) and \( \sigma_e \) for three fog spectra with liquid water content of 0.1, 0.15 and 0.2 \( g\cdot m^{-3} \), at 51 wavelengths from 0.35 to 90 \( \mu m \); (2) Deirmendjian (1969), who computed \( \sigma_e \) for water cloud models C1, C2, C3 in the \( \lambda = 0.45 - 16.6 \) \( \mu m \) interval; (3) Deirmendjian (1973), who computed \( \sigma_e \) for water cloud models C1 and C5 in the \( \lambda = 1 - 100 \mu m \) interval; (4) Shettle and Fenn (1979), who computed \( \sigma_s, \sigma_a, \sigma_e, \bar{\omega}, g' \) as well as of disp, \( a_3 \) and \( a_4 \) for four fog models; (5) Clay and Lenham (1981), who made measurements of the optical depth in the \( \lambda = 0.53 - 10.1 \) \( \mu m \) interval, during six fogs.

**4. Conclusions and remarks**

1) In the limits of the sample of spectra used, both spectra and derived quantities show no regularities which justify the definition of typical spectra and values for each fog type, or for each fog group selected according to \( W \) or \( V_m \). Findings indicate that the size spectrum in highly sensitive to the processes which drive its formation and evolution, so that in fog models spectra have to be determined at each time and point during the fog evolution, by describing the relevant dynamical, thermodynamical, radiative and chemico-physical processes (Brown, 1980; Forkel et al., 1987), and the linked quantities have to be accordingly computed.

2) Results concerning mean optical properties of a sample of 239 spectra, at 74 wavelengths from 0.35 to 90 \( \mu m \), have been presented. Computations have been oriented to radiative transfer purposes, and specifically to the \( \delta \)-Eddington approximation for the phase function.

3) The droplet size spectra used have been measured through different sampling techniques which
present different values of the lower resolution radius $r_m$ ($r_m = 0.3, 1$ and $2 \mu m$). The consequences of omitting small droplets are different among the various quantities considered, because of their different dependence on radius. Garland (1971) and Kunkel (1981) evaluated the effect on $\sigma_a$ and $W$, at visible wavelength, while Corradini and Tonna (1981) considered the effect on the $\sigma_a - W$ correlation, at wavelengths from 5 to $30 \mu m$; results show that $W$ is unaffected, $\sigma_a$ is reduced by up to $30\%$ of its true value, and the correlation coefficients between $\sigma_a$ and $W$ lower, but without substantially altering the meaning of the data.

Furthermore, the limited number of spectra available did not permit them to be classified according to more detailed criteria, e.g., according to the fog type and the height. Nevertheless, on account of the well accepted meaning of our data, of their agreement with previous published data and of their consistency (all data have been computed from the same sample of spectra), we assume them to be significant in promoting an understanding of fogs.

Acknowledgments

I warmly thank Prof. M. Tanaka, Upper Atmosphere Research Laboratory, Tohoku University, Sendai, Japan, who gave me some valuable hints for the present work.

References


Tonna, G. and C. Valenti, 1983: Optical attenuation coefficients and liquid water content relationship in fog, at seventy-four wavelengths from 0.35 to 90 $\mu m$. Atmos. Environ., 17, 2075–2080.


霧粒の粒径分布 239 例を用いた霧の雲物理的性質と光学的特性の研究
G. Tonna
(Instituto di Fisica dell’Atmosfera, CNR, Roma, Italy)

谷露・移流露および放射露の計 239 の霧粒の粒径分布について、霧粒の平均半径など雲物理に関する諸量を計算し、さらにこれらの霧による散乱係数などの光学的諸量を 0.35 から 90μm の間の 74 波長についても計算により求めた。求めた諸量について統計的処理を行ったところ、谷露・移流露および放射露の霧粒の粒径分布や光散乱特性などの諸量の平均値を定めることはできるが、それぞれが大きな変量幅を持っているため、これら 3 種の霧を統計的に区別することは難しいことが分かった。同様に、露水圧や視程で統計量を区別することも難しいことが分かった。したがって、サンプル全体としての平均的諸量を示すことになる。