FREQUENCY DISTRIBUTION OF DUST CONCENTRATION IN BARBADOS AS A FUNCTION OF AVERAGING TIME

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Abstract—Two sets of daily-averaged dust concentration data from Barbados, West Indies, have been analyzed to determine the effect of averaging time, ranging from 1 to 7 days, on the dust concentration frequency distribution. On each of the time scales examined, the frequency distribution is characterized as a bimodal lognormal distribution. The major effects of increasing the averaging are a major reduction in the percentage of the samples represented by the lower of the two modes and a significant increase in the geometric mean concentration of that mode. Consequently, predictions of the distributions on a shorter time scale are likely to substantially underestimate the frequency of low concentration samples.

Key word index: Aerosols, dust, frequency distribution, statistics, Barbados.

INTRODUCTION

Recently, an effort was undertaken to determine more precisely the frequency distribution of continental dust concentrations over the oceans. A major portion of the existing long-term data sets is derived from samples collected over periods on the order of a week; prominent among these data sets are those from the extensive North and South Pacific aerosol networks (Uematsu et al., 1983), that from Mauna Loa (Parrington et al., 1983), and that from the South Pole (Maenhaut et al., 1979). For many purposes, the frequency distributions on a daily or shorter time scale would be more appropriate. Although significant differences between the weekly and the daily frequency distributions are expected to occur, the magnitude and form of those differences is not clear.

To get some idea of the effects of changing the averaging time, dust concentration data from Barbados, West Indies, were analyzed on time scales of 1, 2, 4 and 7 days. The intermediate time scales were included to provide a clearer picture of the progressive changes in the distribution as the averaging time was increased.

DATA SETS AND STATISTICAL METHODS

The extensive set of dust concentration data from Barbados has been recently presented and discussed by Prospero and Nees (1986). All of the data used here were determined from samples collected on Whatman-41 filters. The dust concentration is calculated from the weight of the residue less that of the average blank after extracting the water-soluble components and then ashing the filter at 500°C (Prospero and Nees, 1986; Uematsu et al., 1983). For this analysis, we have used three separate groups of dust concentration data from Barbados. The first group is composed of all of the data collected from 1979 to 1981, 1037 daily samples. The second group consists of 345 daily samples collected over a continuous 1-year period beginning in 1984 and ending in 1985. One, 2, 4 and 7-day averages were computed for each of these two groups. The third group consists of 103 weekly averages from samples collected throughout 1982 and 1983. The distribution from this latter set was determined for comparison with the 7-day averages from the first two groups.

Summertime dust concentrations in Barbados have previously been shown to be well characterized by bimodal lognormal distributions (Savoie and Prospero, 1977). This bimodality is also apparent in the longer term distributions which we are considering here. Although a trimodal distribution determined by the truncation method (Essenwanger, 1976) produced better fits to several of the cumulative frequency distributions, the addition of a third mode could not be justified on the basis of standard chi-square tests. Recall that without simplifying assumptions, the addition of a single mode requires the addition of three adjustable parameters: fraction of samples, geometric mean and standard geometric deviation. Hence, the goodness of fit must increase substantially for the additional mode to be significant.

The composite distributions were decomposed using the moments method of Rao (1952; reported by Essenwanger, 1976) in which the standard geometric deviations of the separate distributions are assumed to be equal to one another. This method is simpler to use than the truncation method and, for the several sets which were checked, the two methods gave essentially equivalent results.

RESULTS AND DISCUSSION

The cumulative frequency distributions of the daily and weekly averaged dust concentrations for the 1979–1981 and 1984–1985 sample sets are presented in Fig. 1 (for clarity, the intermediate distributions have
not been included. Comparisons of the daily and weekly distributions reveal two major features. First, the inflection point in the weekly distribution occurs at a much lower cumulative percentage. This attribute indicates that the percentage of samples in the lower of the two concentration modes is considerably smaller for the weekly averages than for the daily. The percentage in the higher mode must obviously increase to compensate. Second, the slopes near the ends of the plots are flatter for the weekly averages than for the daily. This decreased slope reflects the reduction in standard deviation with increasing averaging time.

Although the cumulative frequency distributions are statistically the best representation of the data sets, the major attributes of the distributions are usually clearer in the frequency histograms. However, one must beware of putting too much emphasis on the apparent peaks in the histograms. Particularly in small data sets, spurious peaks often occur. The apparent splitting of the low concentration mode in the 1984–1985 7-day average histogram (Fig. 2), for example, is a consequence of the step-function character of the cumulative frequency distribution. For such data sets, the appearance of the histogram is very sensitive to the size of the bins and location of their boundaries; when a few concentrations are very similar, a small shift of the boundary can result in all of them being transferred to an adjacent bin. This characteristic is gradually smoothed as the size of the sample set increases. Although the apparent agreement between the his-

Fig. 1. Cumulative frequency distributions of the daily and weekly averaged dust concentrations during two periods in Barbados.

Fig. 2. Frequency histograms of the 1984–1985 dust concentrations in Barbados for four different averaging times. The smooth curves are the best fit bimodal lognormal distributions as obtained by the moments method.
tograms and the bimodal distributions could have been substantially improved by a judicious choice of the size and location of bins for each data set, such a procedure would have introduced considerable subjectivity and bias into an otherwise objective analysis. The same bin sizes and locations were used throughout this investigation in order to make direct comparisons easier.

Although the effects of averaging time on the frequency histograms are perceptible in the 1984–1985 data, they are more clearly shown in the 1979–1981 set (Fig. 3), which contains a factor of three more data. The most obvious effect is the gradual erosion of the low concentration end of the histogram as the averaging time increases. In the 1979–1981 data set, for example, the percentage of the concentrations which are less than 1 μg m⁻³ decreases in order from 21%, to 17%, 13%, and 10%, as the averaging time increases from 1 day to 2, 4 and 7 days, respectively. A similar decrease occurs in the 1984–1985 data, from 23% for the daily to 13% for the weekly averages. The reverse occurs at the opposite end of the concentration scale. In the 1979–1981 data set, concentrations greater than 10 μg m⁻³ account for 32%, 33%, 35% and 40% of the samples in the 1, 2, 4 and 7-day averages, respectively. An analogous increase from 47% to 55% occurs with the 1984–1985 data.

Additional insight is gained by looking at the changes in the parameters of the low and high concentration modes as a function of averaging time (Table 1). The most dramatic change is in the relative numbers of samples in the two modes. For the daily averages, the ratio of the number of samples in the low mode to that in the high mode is about 0.75. The ratio decreases to between 0.3 and 0.5 for the weekly averages. Second, the geometric mean of the low dust mode increases by about 25–30% in contrast, that of the high dust mode decreases by only about 10%. Third, the standard geometric deviations decrease by about 10–15%.

The major changes in the distributions are primarily a consequence of a single mathematical fact: the logarithm of the arithmetic mean of two values is always closer to that of the higher value. The effect is most pronounced when the two values are widely separated. For example, averaging a value of 0.1 with one of 100 yields 50 which is only a factor of two lower than 100 but is a factor of 500 higher than 0.1. In the frequency histograms in this report, the bin widths are 0.25 log units. Hence, if two values are averaged together, the result will be, at most, 1.2 bin units below the higher value. This feature can have a substantial effect on the relative numbers of samples in the low and high modes. If a concentration in the low mode is averaged with one in the high mode, the result will most often contribute to the high concentration mode at the longer averaging time. By a similar set of arguments, one should expect the low mode geometric

![Frequency histograms for different averaging times](https://example.com/image1)

![Frequency histograms for different averaging times](https://example.com/image2)

![Frequency histograms for different averaging times](https://example.com/image3)

![Frequency histograms for different averaging times](https://example.com/image4)

**Fig. 3.** Frequency histograms of the 1979–1981 dust concentrations in Barbados for four different averaging times. The smooth curves are the best fit bimodal lognormal distributions as obtained by the moments method.
Table 1. Daily vs multiple-day average dust frequency distributions in Barbados, West Indies

<table>
<thead>
<tr>
<th>Data set</th>
<th>N</th>
<th>Low mode geo. mean (µg m⁻³)</th>
<th>High mode geo. mean (µg m⁻³)</th>
<th>Std. geo. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979–1981</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td>1036</td>
<td>0.991 (42.3)</td>
<td>11.27 (57.7)</td>
<td>2.166</td>
</tr>
<tr>
<td>2-day</td>
<td>514</td>
<td>1.071 (38.8)</td>
<td>10.95 (61.2)</td>
<td>2.073</td>
</tr>
<tr>
<td>4-day</td>
<td>254</td>
<td>1.216 (32.0)</td>
<td>9.90 (68.0)</td>
<td>2.065</td>
</tr>
<tr>
<td>7-day</td>
<td>142</td>
<td>1.232 (25.9)</td>
<td>9.91 (74.1)</td>
<td>1.906</td>
</tr>
<tr>
<td>1984–1985</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily</td>
<td>345</td>
<td>0.962 (42.3)</td>
<td>23.05 (57.7)</td>
<td>2.284</td>
</tr>
<tr>
<td>2-day</td>
<td>179</td>
<td>0.987 (40.7)</td>
<td>24.03 (59.3)</td>
<td>2.016</td>
</tr>
<tr>
<td>4-day</td>
<td>92</td>
<td>1.081 (36.5)</td>
<td>22.92 (63.5)</td>
<td>1.955</td>
</tr>
<tr>
<td>7-day</td>
<td>54</td>
<td>1.279 (32.4)</td>
<td>20.93 (67.6)</td>
<td>1.961</td>
</tr>
<tr>
<td>1982–1983</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-day</td>
<td>103</td>
<td>2.277 (24.7)</td>
<td>23.76 (75.3)</td>
<td>2.128</td>
</tr>
</tbody>
</table>

% Refers to the percentage of the samples in each of the two modes.

CONCLUSIONS

The results presented above indicate that variations in the averaging time can have a substantial effect on the concentration frequency distribution of a species. In the present example, dust in Barbados, the major changes with increasing averaging time are: (1) a substantial decrease in the percentage of values in the low concentration mode; and (2) a substantial increase in the geometric mean concentration of the low mode. The effect of each of these changes is to reduce the percentage of low concentration values. Hence, the use of data on one time-scale to predict the relative abundance of concentrations on a shorter time scale would result in a significant underestimation of the relative frequency of low concentrations. This would be a major problem when dealing with concentrations near the detection limit of a procedure; on shorter time scales, concentrations at or below the detection limit are likely to be much more frequent than predicted.

There are two properties of the data sets considered here which are of significance to the magnitude of the averaging time effect: (1) the distributions are clearly bimodal with about an order of magnitude separation between the geometric means of the two modes; and (2) there is a significant autocorrelation within the concentration time series. The latter property reflects the fact that high dust concentrations are associated with processes occurring on time scales that are longer than the averaging time; dust transport to Barbados varies on a number of time scales ranging from about a day to more than a year (Prospero and Nees, 1986).

If a bimodal time series exhibits a very high autocorrelation (first order, at lag one), then adjacent concentrations will usually be within the same mode, i.e. low concentrations next to low concentrations and high concentrations next to high concentrations. In this case, there will be little reduction in the percentage of concentrations in the low mode as long as the averaging times are within the time scale of the autocorrelation. Conversely, a very low degree of autocorrelation would indicate that low concentrations are quite likely to be averaged with high concentrations. Since this average is usually in the high mode, the percentage of the resultant concentrations in the low mode will decrease substantially with increasing averaging time. Note that the depletion in the percentage of low concentrations would also occur in a unimodal time series with a low autocorrelation. Because there are no separate high and low modes in the latter case, the result would simply be a sharper increase in the geometric mean and decrease in the standard geometric deviation.

Clearly, the results obtained for dust in Barbados do not have universal application. However, over some broad areas of the world ocean, dust transport is similar to that in Barbados in several respects. In most of the regions which have been studied, the magnitude of the dust transport exhibits a strong seasonal cycle. The transport tends to be sporadic with large concentrations occurring in the wake of dust storms over upwind arid and semi-arid regions. An analysis of the dust concentrations at individual stations in both the North and South Pacific indicates that the bimodality of dust concentration frequency distributions is very common. Given these similarities, it is likely that the variations of those distributions with averaging time are analogous to those in Barbados.

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REFERENCES


