intermittent. Their calculations also suggest that intermittent entrainment cannot yield broad droplet distributions and agree with us that the results of Baker et al. (1980) result largely from the unrealistic assumption that entrainment removes by evaporation equal fractions of all droplet sizes. Furthermore, Baker et al. (1982), in their latest paper, admit that they find no evidence from their measurements in clouds capping a mountain top that the droplet spectra were broader than those calculated on the basis of adiabatic ascent with no mixing. Moreover the largest droplets were associated with the highest total droplet concentration and therefore could not have been produced by evaporation effects.

REFERENCES


A study of dewfall in an arid region: an analysis of Wangara data

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SUMMARY

Micrometeorological flux-gradient relations have been used to deduce average evaporation rates for most hours of the Wangara experiment, using net radiation and ground heat transfer values. At night, dewfall is found to have been a common occurrence, at rates that averaged about 0.015 mm h⁻¹ and sometimes approached (but never exceeded) the value of about 0.07 mm h⁻¹ that has been proposed as a natural limit. The average nocturnal dewfall was about 0.22 mm. During the 44 days of the experiment, about 20 mm of rain fell at the central site, augmented by about 9 mm of dewfall. Evaporation amounted to about 26 mm of water.

1. INTRODUCTION

The Wangara data set of Clarke et al. (1971) is one of the most widely used sources of high quality information on the evolution of the planetary boundary layer. Recently, Hess et al. (1981) have reviewed the Wangara experiment and many of its derivative studies, and have presented plots of some quantities not presented previously. In particular, a graph of available ground water is given, from which data on dewfall can be extracted. Such information is of considerable interest, since hour-by-hour studies of dewfall rates in arid regions are quite rare. Here, dewfall rates will be documented and compared with other data.

The analysis will be based on a set of heat and momentum fluxes that have been inferred from the relatively sparse Wangara micrometeorological data. The derivation of surface heat fluxes is too detailed and too specialized for presentation here, however, because of the frequent need for
Wangara surface flux data, the resulting smoothed values have been tabulated elsewhere (Hicks 1981).

2. Data analysis

An earlier analysis of the Wangara surface boundary layer data (Hicks 1976) showed that the dimensionless wind gradients $\phi_{nu}$ agreed well with the relations summarized by Dyer (1974), although some modification of the usual log-linear formulation for stable stratification seemed desirable. The intent of the earlier analysis was not only to investigate flux-gradient relations, but also to demonstrate that these formulations are adequate for evaluating surface fluxes in cases for which no eddy fluxes were measured during the Wangara experiment. Assuming that the flux-gradient relations for both momentum and heat are known, it is then relatively easy to evaluate sensible heat fluxes from the available wind and temperature gradient information (the latter over the interval 1-4 m).

Routine observations of net radiation and of the ground heat transfer are listed in the Wangara report. Radiation values were obtained using a ventilated, polyethylene-shielded net radiometer, and ground heat fluxes were measured by a network of flux plates located close to the surface in order to minimize storage terms. Thus, there is a good and nearly continuous record of the quantity $(R_n - G)$, which can be equated to the sum of sensible, $H$, and latent, $L_e E$, heat fluxes (here, $L_e$ is the latent heat of vaporization of water and $E$ is the evaporation rate).

![Figure 1. Changes in ground water inferred from Wangara heat fluxes. Periods A, B, C, D and E were times when the surface at station 5 was visibly moist (see Clarke et al. 1971, appendix 1). Numbers associated with each such occasion indicate the quantity of rainfall (mm). Lines drawn through data indicate a dewfall rate of 0.07 mm h$^{-1}$.](image)

Figure 1 shows the accumulated change in soil water derived from an analysis of the surface heat budget, using the sensible heat fluxes listed by Hicks (1981), augmented by the precipitation observations reported by Clarke et al. (1971) for the central Wangara site. Data are presented as four-hour averages, and are derived directly from the smoothed evaporation rates calculated as $(R_n - G - H)/L_e$, which are frequently negative at night, indicating dewfall. Note that Fig. 1 is a modification of a diagram presented earlier by Hess et al. (1981).

Strong daytime evaporation and slow nocturnal dewfall are clearly evident features of Fig. 1, as are also the three main periods of isolated rainfall (on days 10, 17 and 35/36). Following each of these rainfall occasions, a period of stronger evaporation is evident, at an average rate that appears to depend on the amount of precipitation which preceded it. It is also apparent that dewfall was largest following days with high evaporation rates. The diagram suggests that the ground accumulated water during the experiment, to the extent of about 3 mm; however, little confidence can be associated with this because of the need to extrapolate through the mid-experiment break (as indicated by the dashed line in the diagram).

3. Wangara dewfall

Table 1 lists the quantities of dewfall that are indicated at the central Wangara site, station 5, by the present analysis, for every night for which sufficient information is available. The average amount is 0.22 mm, with a standard deviation of 0.19 mm.

Monteith (1963) predicts that the short-term dewfall rate should not exceed about
TABLE 1. AVERAGE NOCTURNAL DEWFAA (in mm) EVALUATED AT STATION 5 AS 

\( (R_o - G - H) \frac{y}{L_o} \).

<table>
<thead>
<tr>
<th>Day</th>
<th>Dewfall</th>
<th>Day</th>
<th>Dewfall</th>
<th>Day</th>
<th>Dewfall</th>
<th>Day</th>
<th>Dewfall</th>
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<tbody>
<tr>
<td>1</td>
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<td>11</td>
<td>0.57</td>
<td>25</td>
<td>0.04</td>
<td>35</td>
<td>0.14</td>
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<td>2</td>
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<td>0.12</td>
<td>36</td>
<td>0.31</td>
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</tr>
<tr>
<td>4</td>
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<td>14</td>
<td>0.17</td>
<td>28</td>
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<td>0.54</td>
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</tr>
<tr>
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<td>16</td>
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<td>30</td>
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<tr>
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<td>17</td>
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<td>31</td>
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<td>41</td>
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<tr>
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<td>20</td>
<td>0.19</td>
<td>34</td>
<td>0.27</td>
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<td></td>
</tr>
</tbody>
</table>

0.07 mm h\(^{-1}\). The Wangara data support this result. Inspection of Fig. 1, where a line with slope of 0.07 mm h\(^{-1}\) is drawn for comparison, indicates that only rarely do any of the Wangara data approach this limit. The period from day 11 to day 15 appears to have had a high frequency of near maximum dewfall rates.

Figures 2 and 3 show the limits on observed dewfall rates more clearly. In Fig. 2, average dewfalls over selected 3 h periods have been used to construct frequency distributions which show a nearly Gaussian form through most of the night. The frequency distributions for data over the three nocturnal periods are quite similar; the 0300–0600 data are probably influenced considerably by

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**Figure 2.** Average dewfall rate frequency distributions, for three-hour periods 1800–2100, 2100–2400, 2400–0300 and 0300–0600.
effects near sunrise. Figure 3 combines all the 1800-0300 data to show the close agreement with a normal frequency distribution. For the conditions of this particular experiment, the mean dewfall rate was about 0.015 mm h\(^{-1}\), with less than one percent probability of exceeding Monteith's limiting value of 0.07 mm h\(^{-1}\).

It is of passing interest to note that there is no obvious indication of a time dependence of dewfall rates throughout the night, once transition periods near dusk and dawn are avoided.

As is evident in Fig. 1, the greatest dewfalls tended to occur after days of greatest evaporation, which is not surprising since these occasions were probably the most humid. Thus, dewfall appears to play the role of a natural moisture redistribution mechanism, by which water deposited in highly localized precipitation events is spread over a substantially wider region during the following days. The Wangara report indicates a total of 20 mm of precipitation during the experiment at station 5; dewfall appears to have contributed a further 9 mm at this location.

The station 5 dewfall data support the cloud cover dependence that would be anticipated intuitively. Figure 4 demonstrates that most dewfall occurred with little cloud. Under complete cloud cover, the average dewfall appears to be about 25% of the clear-sky value.
4. Conclusions

When combined with observation of net radiation and ground heat transfer, nocturnal heat fluxes derived from Wangara micrometeorological data provide estimates of surface condensation that sometimes approach but do not exceed the limit of 0.07 mm h⁻¹ proposed by Monteith (1963). The average dewfall amounted to about 0.22 mm per night, so that during the course of the experiment about 9 mm of dewfall occurred. In comparison, 20 mm of precipitation was recorded during the experiment at the central site, station 5.

Acknowledgments

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References


Book Reviews


Multi-author books often create problems for readers, with variations in notation, contradictory viewpoints of which authors are not aware, unsystematic treatment, omissions or duplications and so on. The editors are to be congratulated in this case for having done an excellent job of coordination particularly in sequence of argument, and uniformity of notation and indexing. The book is designed as a course rather than as a conference report, and in this it is successful. Experts present all the basic ideas in a good academic style in which details of logic etc. are given due place. This is important anyway but more so in this case because the subject is not really a useful one.

That may seem a hard thing to say, yet it is not intended to denigrate the book as a text on the theory of diffusion and the instrumental techniques of observation. These are basic to understanding the subject and getting out of computers what can now usefully be obtained from them. This kind of treatment is part of the intellectual background needed to understand the subject, but it is of very little use to the engineer or specialist in another field, who merely wants to know answers and have formulas he can use in practice without further bother.

With so much going on out of doors which makes pollution or is affected by it, the subject is slowly becoming better understood, but there is still a long way to go before the users of the results can be said to understand why prediction is less accurate than weather forecasting (because it has a further degree of complexity) and that precision is not advisable anyway.

There was a valuable but brief panel discussion at the end of the meeting which the book records, and there some of the basic shortcomings of the theory are aired. Concern arises because it is easier and better to measure pollution and ignore theory than to measure something else and estimate it from that. All predictions are really projections from specific past experiences whereas in Newton's laws of mechanics we have rules established so that we can safely believe in and use them without reference to any occasions. Diffusion modelling is not as bad.