Eddy-Flux Measurements over a Small, Irrigated Area

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ABSTRACT

During the summer of 1961, the vertical transfer of water vapor and sensible heat was determined at a height of 4 m over an irrigated field at Davis, Calif. Simultaneous determinations of evaporation at the surface were obtained with a 20-ft weighing lysimeter, and the corresponding sensible heat transfer computed using an energy balance approach.

A comparison of the two methods of determining these vertical fluxes showed excellent agreement early in the summer, but significant differences appeared as the season progressed. These could be attributed to severe contrasts developing between the heavily irrigated site and the surrounding areas, which, with no rain occurring, gradually dried out.

The fetch available was of the order 50-190 m depending on wind direction. The results clearly indicated that under the conditions of this experiment, the vertical fluxes were not constant with height, and a condition of horizontal uniformity did not exist.

1. Introduction

The vertical transfer of water vapor and sensible heat in the lower layers of the atmosphere is usually considered in the light of a condition of horizontal uniformity. This concept requires that the fluxes are constant, both in the horizontal and the vertical; and that the horizontal gradients of wind, temperature, and humidity can be regarded as negligible. The vertical profiles of these parameters will then be independent of location in the horizontal.

Such conditions do not apply at a "leading edge" when air moves from a dry area over a wet area. There is, clearly, a transition regime between two states of horizontal uniformity, but little is known about the horizontal extent of this regime.

It has sometimes been considered that measurements up to a height of 1/30 to 1/50 of the fetch can be regarded as being within the uniform regime.

During the period, 26 April to 21 August 1961, eddy-flux measurements of water vapor and sensible heat transfer were made at a height of 4 m over an irrigated, rye-grass field at Davis, Calif. The equipment used, known as the "Evapotron," employs the eddy-correlation principle, the validity and accuracy of which has already been established by Swinbank (1951) and Dyer (1961). Simultaneous measurements of evaporation

were obtained from a 20-ft weighing lysimeter (Pruitt and Angus, 1960), together with measurements of net incoming radiation.

A comparison of the two techniques of determining vertical fluxes gives some insight into the basic problem posed above.

2. Conditions of the experiment

The eddy-flux equipment was installed close to the lysimeter, both being situated somewhat to one side of the experimental site, which measures 350 m by 150 m. The eddy-flux observations consisted of a series of 15-min runs, and lysimeter and net incoming radiation data were obtained for the identical periods.

The wind direction varied considerably during the observing periods, so that the average fetch ranged between 50 m and 190 m.

No rain occurred throughout the late spring and the entire summer season, the last significant rainfall being 0.37 inch on 21 April. During the experimental period, eight irrigations of the field site were carried out supplying a total of 20 inches of water.

Other sites surrounding the one employed carried green crops until late spring, but in general, were fallow and unirrigated for the remainder of the experimental period. Consequently, a severe contrast in soil moisture between the experimental site and its surroundings developed as the season progressed.

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TABLE 1. Comparison of water vapor flux, E_4 , at 4 m height, and evaporation, E_0 , at the surface.

Date	Pacific standard time (hr)	Total observing period (min)	E_4 mW cm ⁻²	E_0 mW cm ⁻²	R_n mW cm ⁻²
15 May	1100-1400	60	52.2	49.4	56.7
22 May	1250-1350	45	32.9	45.2	65.8
30 June	640-1340	165	32.3	57.0	50.7
27 July	1410-1700	90	22.9	42.9	39.9
21 August	1130-1248	75	19.6	27.7	57.4

3. Evaporation measurements

Table 1 presents a summary of the results for those occasions on which a well-documented series of observations were obtained. E_4 is the water-vapor flux at 4 m, E_0 the evaporation at the surface, and R_n the net incoming radiation. All quantities are expressed as an average over the periods of observation in the units mW cm⁻².

Early in the season (15 May) there is excellent agreement between the two methods of determining evaporation. At this time there was little contrast between the irrigated site and the surroundings.

As the contrast developed, however, significant differences appeared between E_0 and E_4 in the direction that would be expected. It can readily be shown that neglecting horizontal diffusion and storage changes,

$$E_0 - E_4 = L \int_0^{400} \rho u \frac{\partial q}{\partial x} dz, \quad (1)$$

where L is the latent heat of vaporization, ρ is the air density, u the wind-speed, and $\partial q / \partial x$ the horizontal gradient of specific humidity at height z , at the location of the measuring equipment.

Under the circumstances prevailing during the summer $\partial q / \partial x$ would be positive, and hence $E_0 > E_4$, as observed.

Considerable facilities are necessary to assess the righthand side of Eq (1), and these were not available until this program was almost completed. However, careful measurements of wind, temperature and

humidity profiles were made during the period 1330 to 1600 hr on 3 August, and the righthand side of Eq (1) computed by graphical integration. These revealed that, $E_0 - E_4$ was, on this occasion, of the order 20-30 mW cm⁻², thus lending considerable support to the differences between E_0 and E_4 appearing in Table 1.

The presence of advective effects is evident in that $E_0 > R_n$ on the morning of 30 June, a day with hot, northerly winds; and on the afternoon of 27 July with somewhat cooler, southerly winds. The latter result is typical for afternoons during the summer, and inversions as great as 6F between the surface and a height of 1 m were frequently observed at the lysimeter site during the mid-afternoon.

4. Sensible heat transfer measurements

Table 2 reports the average values of sensible heat transfer at 4 m height, H_4 , and at the surface, H_0 , obtained for identical periods during the hours of measurement. Values of H_0 were obtained from the energy balance equation,

$$E_0 + H_0 = R_n - G, \quad (2)$$

where G is the average heat flux into the ground measured at a soil depth of 1 cm.

H_0 cannot be determined with very great precision since, in general, H_0 was much smaller than E_0 and R_n . Values of H_0 estimated for 26 April, 15 May and 22 May are somewhat uncertain since ground flux measurements were not then available.

As before, the evaporation measurements consisted of a series of 15-min observations. As in the evaporation case, significant differences appear between H_0 and H_4 .

In a manner similar to Eq (1) we can write,

$$H_0 - H_4 = C_p \int_0^{400} \rho u \frac{\partial T}{\partial x} dz, \quad (3)$$

where C_p is the specific heat of air at constant pressure and $\partial T / \partial x$ the horizontal temperature gradient at height z . Horizontal diffusion and storage changes can of course be again neglected.

TABLE 2. Comparison of sensible heat flux at the surface H_0 , and at a height of 4 m, H_4 .

Date	Pacific standard time (hr)	Total observing period (min)	H_4 mW cm ⁻²	H_0 mW cm ⁻²	R_n mW cm ⁻²	E_0 mW cm ⁻²
26 April	1320-1545	165	5.9	(6.2)	42.9	36.2
15 May	1000-1300	60	6.8	(8.6)	59.3	50.2
22 May	1200-1350	105	33.8	(21.4)	65.3	43.4
30 June	650-830	45	-4.5	-5.2	24.2	29.9
	900-1130	105	5.3	-0.8	63.1	63.1
27 July	1450-1740	90	-8.1	-12.0	27.9	39.1
3 August	1415-1600	75	-5.7	-8.2	40.8	47.5
21 August	1230-1300	30	6.3	18.4	54.2	34.0

Since the sensible heat transfer from the wet area to the atmosphere will be less than that for the dry area, $\partial T/\partial x$ will be negative in the initial transition regime so that we would expect $H_0 < H_4$. This is in the observed sense in Table 2. The obvious discrepancy for 21 August is probably due to the lysimeter grass, unlike the rest of the field, being in a somewhat wilted condition following a dry-down run of several weeks.

From the brief, but careful profile measurements taken on 3 August from 1330 to 1600 hr, the RHS of Eq (3) was estimated to be of the order 10–15 mW cm⁻², in suitable accord with the values of H_0 – H_4 found in Table 2.

Further confirmation of the presence of advective effects referred to in discussing the evaporation measurements, is provided by the downward heat fluxes found on a number of occasions.

5. Discussion

It is obvious that under the conditions of this experiment the vertical fluxes of water vapor and sensible heat were not constant with height, and that the horizontal gradients of temperature and humidity were by no means negligible. In short, a state of horizontal uniformity did not exist in the lower layers of the atmosphere even for a fetch as long as 50 m to 180 m.

The notion that measurements taken up to height equal to 1/30 to 1/50 of the fetch are within a regime of horizontal uniformity needs to be more closely examined. This result may offer some hope of reconciling, for example, the conflicting evidence concerning the variation of transfer coefficients with stability, as different sites may well have different characteristics.

It is proposed to expand the scope of the present work in order to discuss the question of horizontal gradients in more detail.

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