1.5 USING SURFACE RENEWAL ANALYSIS TO DETERMINE CROP WATER USE COEFFICIENTS

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1. INTRODUCTION

The surface renewal (SR) method for estimating sensible heat flux from canopies provides a simple, portable, robust, and low-cost method to measure crop evapotranspiration (ET_c) for determining crop coefficient (K_c) values, which are extensively used for irrigation management. Many experiments have been conducted to develop and refine the SR method using raw, high frequency data; however, it is impractical to set up systems with computers in irrigated fields to collect raw data for long periods of time. As a result, a data logger program was written to collect data and calculate the statistical moments needed to analyze for ramp characteristics and to calculate sensible heat flux density (H). During recent years this method was used to measure sensible heat flux density over irrigated pasture, paddy rice, cotton, and a citrus orchard. On a half-hour basis, the latent heat flux density (λE) was determined as the residual of the energy balance equation using measured net radiation, soil heat flux density, and H from SR analysis. The half-hour λE values were converted to ET_c in mm of water and totaled over the 24-h day to obtain estimates of daily ET_c. Then the K_c values were calculated as $K_c=ET_c/ET_o$, where ET_o was calculated using the 24-h sum of an hourly Penman-Monteith equation as recommended by the American Society of Civil Engineers (Walter et al., 2000).

2. METHODS

Paw U and Brunet (1991) introduced the surface renewal (SR) method for estimating scalar fluxes. The method is based on coherent structures, which have sweeps to the surface and ejections from the surface as common features (Gao et al., 1989). While parcels of air are at the surface, they will heat or cool as heat is transferred from or to the canopy elements. The rate of temperature change of these parcels is related to sensible heat flux.

At a single location, a sequence of ejections and sweeps are observed at an instrumented tower or mast. If the sensible heat flux is positive, a parcel of cooler air gusts into a canopy. During the ejection phase, horizontally moving air ascends slowly, so the air resides in the canopy sufficiently long to show some heating. The result is a slow temperature rise in the temperature trace with time, which is terminated by the next gust phase. Under stable conditions, the pattern is reversed, with a slow temperature drop as the air in the canopy is cooled by the canopy elements, and a sudden temperature rise as a gust brings down the warmer air from above the canopy (Gao et al., 1989, Paw U et al., 1992).

For practical purposes, a structure function (Van Atta, 1977) is used to identify ramp characteristics:

$$S^n(r)=\frac{1}{m}\sum_{i=1}^{i=m-j}[T(i+j)-T(i)]^n \qquad (1)$$

where m is the number of points, n is the order of the function, j is the sample lag, and i is the point number. The sample lag corresponds to a time lag (e.g., if f = 8 Hz and j=2, then the time lag is r = 2/8 =0.25 s).

In Paw U et al. (1995), the sensible heat flux density during a coherent structure, was derived as:

$$H'=\rho C_p\frac{dT}{dt}\left(\frac{V}{A}\right) \qquad (2)$$

where ρ is the air density, C_p is the specific heat of air, and (V/A) is the ratio of the volume over the horizontal area of the parcel (i.e., the height of the parcel). Practically, for temperature (T) recorded at the canopy top (h_c), the surface renewal equation is expressed as:

$$H=\alpha H'=\alpha\rho C_p\frac{dT}{dt}h_c \qquad (3)$$

The variable α is a calibration factor to account for a linear change in temperature with height. The time derivative represents the heating during the time period of the ramp only, and during the quiescent period between ramps, no heating occurs. When the ramp dimensions are determined by structure functions, it can be shown that H is given by the following equation:

$$H=\alpha H'=\alpha\rho C_p\frac{a}{d+s}z \qquad (4)$$

where a is the ramp amplitude and d and s are the time period (seconds) of the ramp and the quiescent period between ramps and z is the measurement height (m).

While it is desirable to know α based on physical principles, calibration is required at this time. To calibrate α, sensible heat flux density (H_e) is simultaneously measured with a sonic anemometer in an eddy covariance system. Then the surface renewal sensible heat flux density (H) is determined by calculating the slope of a least squares regression of H_e versus H' through the origin.

The use of a computer to collect high frequency temperature data in the field is impractical. Therefore, the temperature data were not archived in a computer but were processed in a datalogger to output half hour

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means of the 2^{nd}, 3^{rd}, and 5^{th} order moments of the time lag temperature differences. Then the moments are analyzed in a computer to determine a and $d+s$.

Two 76.2 μm diameter thermocouples are mounted at the same height to measure temperature. A sampling frequency of f=4 Hz has given good results. Time lags r=0.25 and r=0.5 s are used for short canopies and r=0.5 and r=1.0 s are used for taller canopies. The current reading and up to four previous temperature readings (e.g., 0.25, 0.5, 0.75, and 1.0 s earlier) are stored in the data logger. For selected time lags, temperature differences are calculated and the 2nd, 3rd and 5th moments of each temperature difference are computed. At the end of a half hour, the means of the three moments are stored in the output table for each of two time lags for both thermocouples (i.e., a total of 12 moments). In addition, net radiation (W m^{-2}) is measured. Two soil heat flux plates are inserted at 0.04 m depth to measure the heat flux (G_2) in W m^{-2} at that depth. Temperature above the heat flux plates is recorded with thermocouples depth at the end of each half hour to determine the change in soil heat storage ΔS above the plates. The heat storage is calculated assuming a volumetric heat capacity for a moist soil. Soil heat flux density at the surface is calculated as: $G = G_2 + \Delta S$. After collection, the data are processed to determine ramp characteristics and H.

3. RESULTS AND DISCUSSION

Figure 1 shows the ET_o, ET_c and K_c values during June and July from a surface renewal experiment over an irrigated pasture. The calibration factor was α=0.58. The ET_c and ET_o values were highly correlated, and the result was a K_c value slightly below 1.00. Since ET_o represents the ET of an irrigated pasture and the experimental site was slightly stressed by less than optimal irrigation, the K_c values seem reasonable.

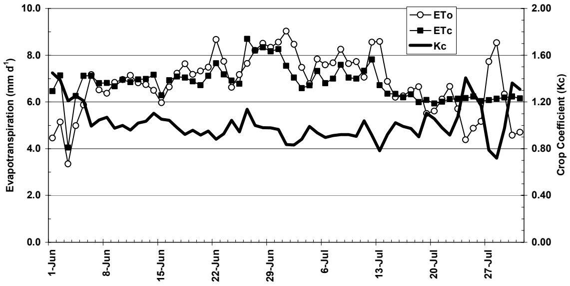

Figure 1. Crop coefficient (K_c) values, reference ET (ET_o) and pasture ET during June and July near Rio Vista, California

Figure 2 shows the ET_o, ET_c and K_c values during April-September 2001 for a naval orange orchard near Lindsay, California. The Kc values increased slowly from about 0.65 to about 0.80 during this period. This is most likely due to continued foliage development during the season. The SR thermocouples were mounted at the canopy height and the calibration factor was α=0.23 for the 4.5 m tall canopy.

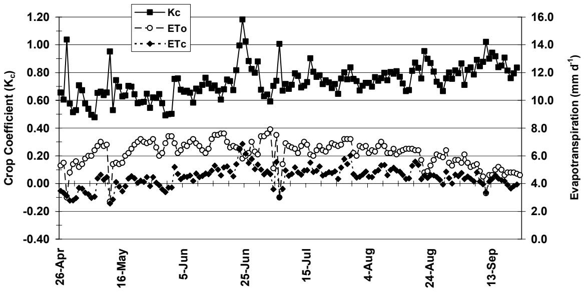

Figure 2. Crop coefficients and ET for a naval orange orchard April-September 2001 near Lindsay, California

4. CONCLUSIONS

The calibrated SR method has proven to be a cost effective useful tool for measuring ETc and estimating Kc values for use in irrigation scheduling. The biggest problems are more related to maintenance of net radiometers and sonic anemometers for calibration than to the high frequency temperature monitoring. A simple data logger program allows for easy data collection in the field.

5. REFERENCES

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