16C.1 AN ENERGY BUDGET EVALUATION OF A RESTORED CALIFORNIA DELTA ECOSYSTEM USING THE EDDY-COVARIANCE METHOD IN COMPARISON WITH THE SURFACE RENEWAL METHOD

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1. INTRODUCTION

The original marshland of the Sacramento and San Joaquin River delta in California was drained for agriculture in the late-1800s (Ingebritsen et al., 2000). Delta characteristics are the result of a levee system completed in 1930 (Thompson, 1957) that divided the area into a series of islands that are now at a lower elevation than the surrounding rivers. Currently, the U.S. Geological Survey (USGS) is conducting experiments on Twitchell Island, which is located in the mid-western portion of the delta. Twitchell Island is a typical delta island with highly organic surface soils and land-surface elevations of 1.5 to 5.1 m below sea level (Owen and Nance, 1962). The overall USGS goal is to mitigate land-surface subsidence by restoring a wetland ecosystem.

The development of delta islands for agriculture led to aerobic conditions that increased microbial oxidation of carbon in the soil, which leads to subsidence (Deverel and Rojstaczer, 1996). By restoring a natural ecosystem, anaerobic conditions will lead to the accumulation of organic carbon and ultimately slow or halt the island subsidence. As part of the Twitchell Island research and to assist in the completion of the overall goal, the USGS is collaborating with the University of California, Davis to carry out energy budget measurements to predict the amount of evapotranspiration (ET) in one of the two restored wetlands (East Pond). The USGS will use the ET rates to create a water budget for maintaining restored wetlands throughout the Delta region.

2. MATERIALS AND METHODS

In 1997, the USGS restored two $2.5*10^4$ m^2 wetlands, planted common tules (*Scirpus acutus*), and began to measure rates of sediment accretion. Both wetlands are permanently flooded, but one has a constant water level of 55 cm (East Pond) and the other has a constant water level of 25 cm (West Pond). Subsequent to flooding, other plants such as duckweed (*Lemna* spp.), cattails (*Typha* spp.), and several submerged aquatic plants have colonized the sites.

A Campbell Scientific Eddy-Covariance (EC) system was installed on the East Pond to measure sensible and latent heat flux. The system includes a CR23X datalogger, CSAT3 three dimensional sonic anemometer, fine wire thermocouple (0.005 inch diameter), LiCorr 7500 open path infrared gas analyzer, HMP45C temperature and humidity probe, Q7.1 net radiometer, three CS107 temperature probe, and HFT-3.1 heat flow transducer manufactured by Radiation and Energy Balance Systems, Inc. The sampling frequency is ten hertz and the program, developed by Ed Swiatek at Campbell Scientific, outputs fifteen-minute means.

Concurrently, a Surface Renewal (SR) system for estimating ET that uses a Q7.1 net radiometer, three CS107 temperature probe, an HFT-3.1, and two fine wire thermocouples (0.03 inch diameter) is located next to the EC system over tules. Two other SR systems measuring the variability of ET are located over different vegetation types and open water.

The SR system is recording data at four hertz and estimates sensible heat flux density (H) and the latent heat flux density (λE), which is calculated as the residual of the energy balance equation:

$$\lambda E = R_n - G - H \quad (1)$$

(Paw U and Brunet, 1991; Paw U et al., 1995; Snyder et al., 1996; Spano et al., 1997) where G is the ground heat flux and R_n is the net radiation. The surface renewal method is being investigated as a possible low-cost alternative for measuring *ET* in the delta.

3. RESULTS AND DISCUSSION

An average daily energy budget analyzed for a five day period from 26 through 30 May 2002 is represented by figure 1. The analysis uses the general form of the energy budget (Eq. 1). When the residual ($R_n - G - H$) is compared with the measured latent energy flux the residual is about 100 W m^{-2} during the morning and about 50 W m^{-2} in the afternoon. Although the reason for the difference is unknown at this time, it is possibly related to the heat flux and storage (G) in the water and soil, which peaks at midday on each day. Since the G term is determined by measuring changes in water temperature and heat flux into the soil at a point, errors could occur if this point is not representative of the G term for the entire pond. This is currently being investigated by monitoring at other locations in the pond.

Figure 2 again shows that the residual *LE* estimate and measured *LE* are in good agreement during midday when the *ET* rate is high. However, at lower *LE* values, $LE + H$ is lower than $R_n - G$ (e.g., in the morning and afternoon).

It is possible that cold water pumped from the river into the warmer pond to maintain the water level could be introducing an energy advection term that affects the energy balance closure. The average inflow velocity for the period of May 24, 2002 to June 4, 2002 is 0.0123 cubic meters per second and the outflow average for the

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same period is 0.0088 cubic meters per second. To determine the magnitude of the horizontal energy advection term, the inflow and outflow water temperature and heat loss and gain from evaporation and condensation need to be determined for the pond. This is currently being investigated.

Surface renewal *H* is calibrated against EC *H* values, so the SR method will give good results as long as there is a good correlation between the EC and SR *H* values and the energy balance closes, see figure 3. Early results indicate that the SR method predicts *H* to within about 50 to 75 W m^{-2} of the sonic anemometer.

4. CONCLUSION

When completed, EC and SR data for a range of plant physiology and weather conditions, including two summers, will be collected. This paper presented preliminary results on the energy balance in a wetland ecosystem and identified concerns and possible solutions to energy balance closure. The observed lack of energy balance closure in the morning and afternoon is most likely related to inadequate measurement of water and soil heat flux and storage or to advection of energy as cold water is pumped into to pond. Both of these possible explanations are currently being investigated.

5. REFERENCES

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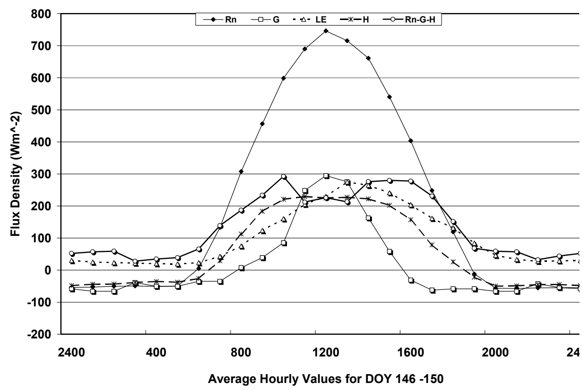

Figure 1. Energy Budget for the wetland ecosystem, including the residual term for May 26-May30, 2002.

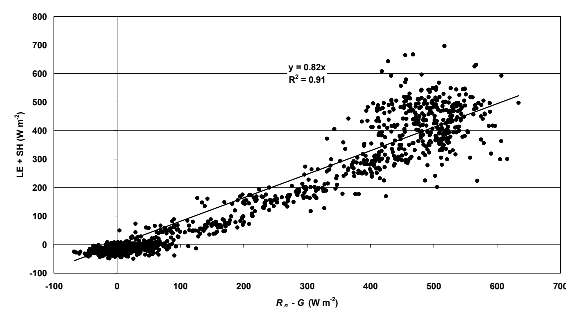

Figure 2. Energy balance closure for EC data from May 24 through July 11, 2002.

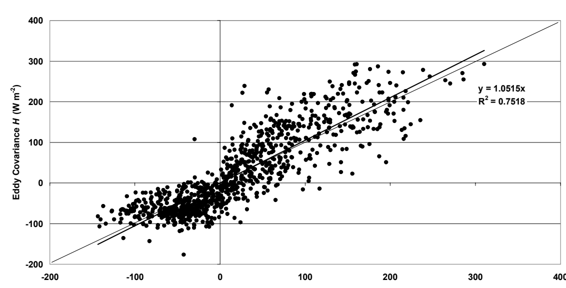

Figure 3. Regression of H from eddy covariance versus calibrated H from surface renewal.