REGIONAL ET ESTIMATION FROM SATELLITES

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ABSTRACT

Crop evapotranspiration (ET) is a major component of the hydrologic system. ET values are used in irrigation water management, water rights allocation, hydrological modeling and water resource planning and management. Traditionally, ET has been estimated using crop coefficient and climatic parameters. Point measurement of ET can also be made through soil moisture monitoring, vapor flux measurement or energy balance using the eddy-covariance method. However, traditional methods will only provide point measurements of ET and do not account for spatial variability of ET in large scale. Recent advances in remote sensing have made it possible to develop regional maps of ET with high precision. A procedure was developed to use the combination of satellite data, ground level weather stations and point measurements of ET, to estimate and develop regional ET maps. The Regional ET Estimation Model (REEM) is based on energy balance at the crop canopy. The model uses incidental values of NDVI, near infrared temperature and albedo, from satellites to calibrate the sensible heat flux equation. The sensible heat flux equation is calculated daily and is modified spatially using well defined nodes in the watershed based on an optimization technique. The REEM based ET values were compared with direct measurement of ET in pecans in Southern New Mexico. The comparison showed that the crop ET can be calculated from REEM model with high precision.

INTRODUCTION

Evapotranspiration (ET) is a key factor in agricultural water management and other hydrologic studies. There are various methods for estimating ET. The most common approach is to calculate reference crop evapotranspiration (ET_o) and

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multiply it by a crop coefficient (K_c) (Allen et al., 1998). The ET_o is generally defined as evapotranspiration from well-watered grass, thus ET is calculated as:

$$ET = K_c \times ET_o \tag{1}$$

Various equations have been developed to estimate ET_o from weather data. These equations range from complex theoretical equations such as Penman-Monteith (Allen et al., 1998) to simpler equations which use one or two climatic parameters (Hargreaves and Samani, 1982, 1985; Priestly and Taylor, 1972). Crop coefficient values have been developed by various investigators based on direct field measurement of evapotranspiration. This traditional method of estimating ET assumes a well watered crop growing under optimum conditions and does not account for the impact of stress where the crop is growing under less than optimum conditions. The stress could be caused by water shortage, disease or other adverse environmental factors.

Recent developments in satellite technology have provided an opportunity to estimate crop ET from remote sensing using surface energy balance (Bastiaanssen et al., 1998a, 1998b; Bastiaanssen, 2000; Allen, 2000). Surface energy balance can estimate ET regardless of stress and does not require detailed soil and crop water information. In addition, estimating ET from satellites is not limited to point measurement of ET, and can be used to provide large scale ET estimates.

METHODOLOGY

The surface energy balance calculates ET as a residual of surface energy budget as:

$$ET = R_n - G - H, \tag{2}$$

where ET is the latent heat flux (W/m^2), R_n is the net radiation flux at the surface (W/m^2), G is the soil heat flux (W/m^2) and H is the sensible heat flux to the air (W/m^2).

Net Radiation

Samani et al. (2004) presented a methodology to estimate daily net radiation by combining clear sky incident solar radiation with short wave radiation from climate stations. The results of daily R_n values estimated from this method was significantly better than those estimated from the standard FAO 56 net radiation equation (Allen et al.,1998).

Soil Heat Flux (G)

Surface heat flux (G) is the component of the energy which enters or leaves the soil. Several empirical equations have been suggested to estimate G. Choudhury (1991) suggested the following equation for dense, short vegetation under daytime conditions and was suggested by Allen et al. (1998) for general application:

$$G/R_n = 0.4e^{-0.5LAI}, \tag{3}$$

where LAI is leaf area index. Choudhury (1991) indicated that factors affecting G/R_n ratio are soil moisture, soil structure and soil texture. The G/R_n ratio can be as much as 0.5 for bare soil, but only 0.03 to 0.05 for a dense vegetation cover (Choudhury, 1991). Clothier et al. (1986) reported that soil moisture did not significantly affect the G/R_n ratio in alfalfa.

Bastiaanssen (1995) suggested the following empirical equation for estimating G/R_n:

$$\frac{G}{R_n} = [\frac{T_s - 273.1}{\alpha}(0.0038\alpha + 0.0074\alpha^2)(1 - 0.98NDVI^4)], \tag{4}$$

where α is surface albedo and T_s is the surface temperature.

Sensible Heat Flux (H)

Sensible heat flux (H) can be calculated using aerodynamic resistance and the difference between surface and air temperature (Tasumi, 2003) as:

$$H = \rho_a C_p \frac{dT}{r_{ah}}. \tag{5}$$

where ρ_a is the air density (kg/m3), C_p is air specific heat (1004j/kg/K), dT is the temperature gradient across the canopy (K). .According to Kustas and Norman (1996), it is more appropriate to use aerodynamic temperature instead of surface temperature. Aerodynamic temperature is defined as the temperature obtained by extrapolating the air temperature profile to an apparent canopy height given by displacement height plus the roughness height. However, accurate estimation of aerodynamic temperature is difficult and therefore surface temperature is used instead of the aerodynamic temperature (Kustas et al., 2000).

Predicting Daily ET

Remote sensing algorithms use satellite images combined with some ground information to calculate regional ET based on surface energy balance (Kustas and Norman, 1996; Kustas et al., 2000; Bastiaanssen et al., 1998a, 1998b; Timmermans et al., 2003). Satellite images can be obtained from various sources which include NASA-Landsat, NOVAA- AVHRR, NASA-MODIS and NASA-ASTER. The satellite data used in calculating ET are normalized difference vegetation index (NDVI), surface albedo and surface temperature. The main advantage of a remote sensing technique is that it can provide regional estimates of surface energy balance, while most conventional techniques are based on point measurements which represent only a small area.

In this study, ASTER images were used due to their high resolution. High resolution images were necessary due to the small and diverse nature of agricultural fields in Southern New Mexico. 3-D eddy covariance systems were installed in a pecan orchard and an alfalfa field. The 5 ha, 21-year old pecan orchard was located about 11 km south of Las Cruces (Lat. 32.225^o N, 106.757^o W). The pecans had an average height of 12.8 m, and average diameter of 30 cm with tree spacing of 9.7 m by 9.7 m.

The alfalfa field was a three year old 8 ha field located about 13 km south of Las Cruces (Lat. 32.206^o N, 106.742^o W). Weather data were obtained from a nearby Campbell weather station. Energy fluxes were measured on 30 min intervals using the eddy covariance equipment. The 30 min values of net radiation (R_n), Soil heat flux (G) and sensible heat (H) were used to calculate daily ET values for the pecan and alfalfa fields using equation 2.

ASTER satellite images for the year 2002 were used to calculate ET values. Clear sky incident short wave radiation (Rs_i) was calculated from equation 2 and was used to calculate incident net radiation (R_{ni}, W/m^2) from equation 1. Equation 8 (Bastiaanssen, 1998a) was initially used to estimate G values from satellite NDVI and albedo, but resulted in large and inconsistent errors. Local soil heat flux data from the year 2001 were used to develop a relationship between ground flux (G) and NDVI (figure 1). The resulting equation is:

$$G/R_n = -0.35\ln(NDVI)-0.0505. \qquad (6)$$

Equation 6 was used to calculate soil heat flux. Combining equations 2, 5 and 6, the daily ET values for pecan were calculated and compared with ET values measured through eddy covariance flux towers (figure 2).

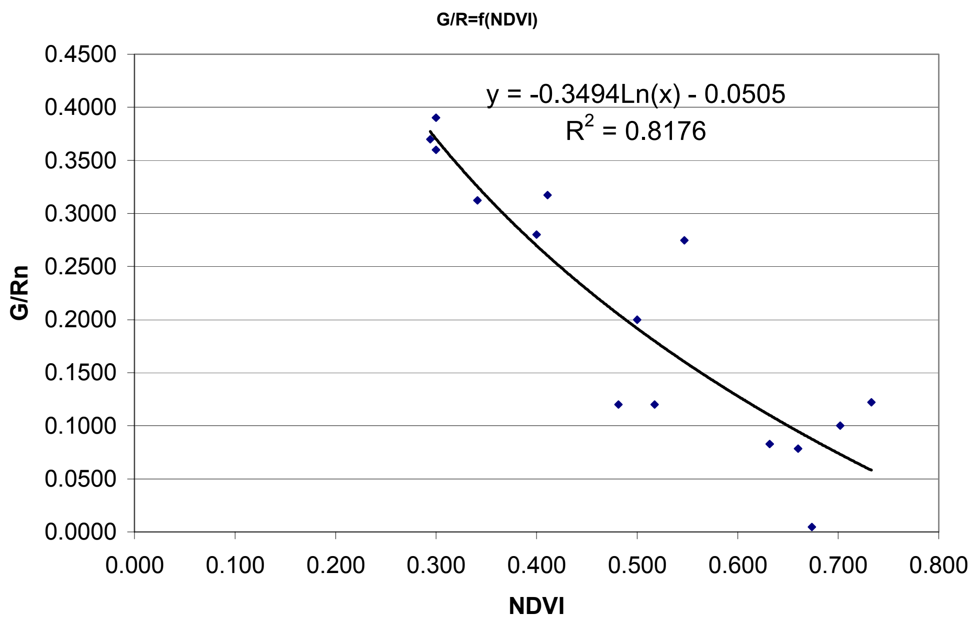

Figure 1. Relationship between (G/R_n) and NDVI.

Figure 2 compares daily ET values calculated with the REEM algorithm and measured by the eddy covariance system. In figure 2, instantaneous sensible heat values (H_i) from the alfalfa field and sensible heat values from a dry field were used to calculate daily ET for the pecan field.

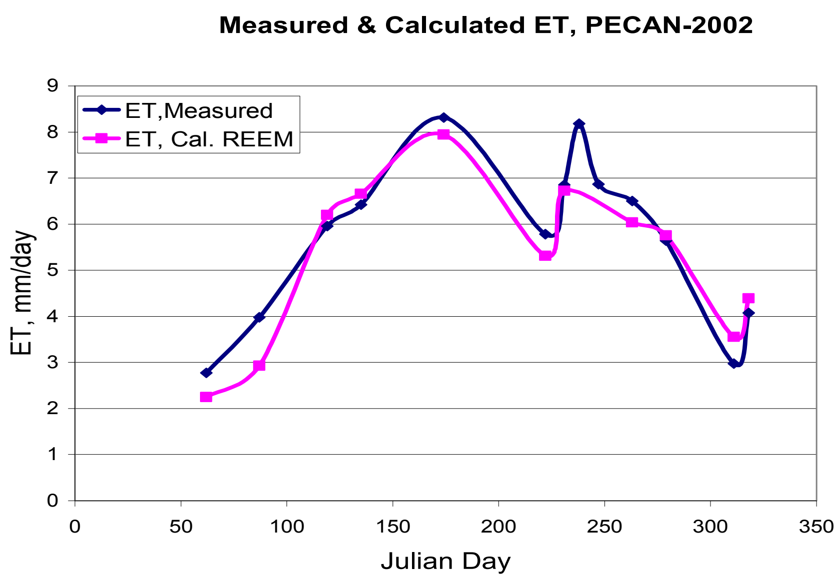

Figure 2. Comparison of ET values predicted from REEM algorithm and measured with 3-D eddy covariance energy flux system.

CONCLUSIONS

A remote sensing algorithm (REEM) was developed using surface energy balance theory. Instantaneous values of albedo, NDVI and near infrared temperature from NASA-ASTER were used to calculate daily ET values for pecans in Southern New Mexico. 3-D eddy covariance flux stations were installed in two fields. The comparison of measured and predicted daily ET values showed that surface ET can be estimated from satellites with good accuracy.

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