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Diurnal Evapotranspiration Estimates in the Walnut River Watershed*

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2B.4 DIURNAL EVAPOTRANSPIRATION ESTIMATES IN THE WALNUT RIVER WATERSHED

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1. INTRODUCTION

Evapotranspiration is an essential component of the surface hydrological balance, but obtaining accurate estimates of the water vapor flux over large terrestrial areas can be difficult because of the substantial temporal and spatial variability in surface moisture conditions that can occur. This variability is often very large in the Great Plains and other portions of the Mississippi River Basin. Nevertheless, variations in soil moisture content, groundwater levels, and runoff in streams and rivers cannot be fully assessed without some knowledge of evapotranspiration rates. Here, observations made at the Walnut River Watershed (WRW), which is near Wichita, Kansas, and has an area of approximately 5000 km^2, are used to improve and test a modeling system that estimates long-term evapotranspiration with use of satellite remote sensing data with limited surface measurements. The techniques may be applied to much larger areas. As is shown in Fig. 1, the WRW is located in the Red River Basin and is enclosed by the southern Great Plains Clouds and Radiation Testbed (CART) of the U. S. Department of Energy's Atmospheric Radiation Measurement (ARM) program.

The functional relationships involving the satellite data, surface parameters, and associated subgrid-scale fluxes are modeled in this study by the parameterization of subgrid-scale surface (PASS) fluxes scheme (Gao, 1995; Gao et al., 1998), which is used in a modified and improved form (PASS2). The advantage of this modeling system is that it can make effective use of satellite remote sensing data and can be run for large areas for which flux data do not exist and surface meteorological data are available from only a limited number of ground stations. In this study, the normalized difference vegetation index (NDVI) or simple ratio (SR) and surface brightness temperature at each pixel for the WRW were derived from advanced very high resolution radiometers data collected by a ground station at Argonne National Laboratory from the National Oceanic and Atmospheric Administration's NOAA-12 and NOAA-14 satellites. The satellite data were subjected to atmospheric corrections for three intensive observation days of the 1997 Cooperative Atmosphere-Surface Exchange Study (CASES-97) experiment, which was conducted in cooperation with the Argonne Boundary Layer Experiments (ABLE) effort and the ARM Program.

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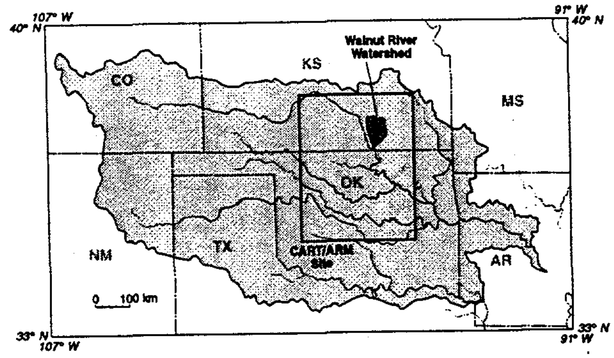

Fig. 1. Geographic location of the Walnut River Watershed.

2. METHOD

Figure 2 outlines the procedures used in PASS2 to estimate daily energy and water vapor fluxes. The inputs included information derived from the latest satellite overpass for cloudless conditions: NDVI^i or SR^i for each pixel i. The relative amount of extractable soil moisture (ESM, θ_s^i) in the plant root zone, or some other measure of the soil moisture distribution in the area, is required for PASS2. Here, estimates of ESM were provided by calculations with PASS1 (Song et al., 1999). Daily standard surface meteorological observations characteristic of the region were obtained from three ABLE automatic weather stations and CASES equipment operating in the WRW: downwelling solar irradiance ($\overline{K\downarrow}$), air temperature ($\overline{T}_a$), relative humidity ($\overline{RH}$), and wind speed ($\overline{U}$). Land use data (USGS, 1990) were combined with NDVI values to estimate the surface roughness length (z_o^i) for each satellite data pixel area.

The diurnal variation of several surface biophysical parameters and meteorological variables was estimated both for each pixel area and as a spatial (regional) mean over the entire WRW (Fig. 2). The surface water vapor conductance (g_c^i), which incorporates the effects of water vapor transfer from the soil surface and vegetative canopies, required observational data on solar radiation, estimated or measured atmospheric water vapor deficit, and previously derived SR^i and θ_s^i. The initial water vapor deficit values represented the spatial means because the pixel-specific values were not available at this step of the model calculations. Friction velocity (u_*^i)

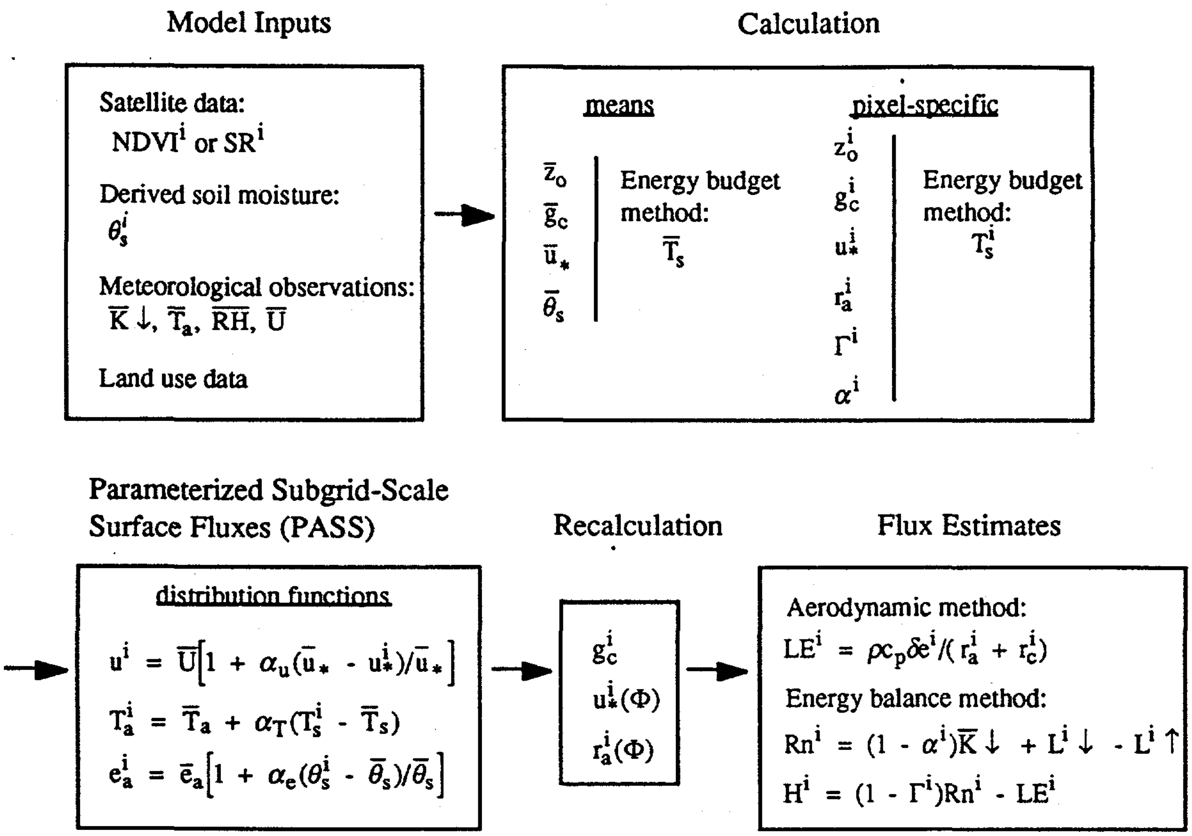

Fig. 2. Flow chart of the procedures used in PASS2 to derive latent heat flux and other energy balance components.

and aerodynamic resistance (r_a^i) were initially estimated on the basis of z_o^i and $\overline{U}$. Calculation of surface albedo (α_i) and soil heat flux ratio (Γ^i) were based on SR^i and the solar zenith angle. The surface temperatures for individual pixels and for the area were calculated with an improved second-order approximation of the energy budget equations (Paw U and Gao, 1988; Gao 1995). Three distribution functions in PASS2 related the pixel-specific values for wind speed, air temperature, and atmospheric vapor pressure (u^i, T_a^i, and e_a^i) to the regional quantities u_*, $\overline{T}_s$, and θ_s with the corresponding empirical coefficients α_u, α_T, and α_e (Gao, 1995). Then g_c^i, u_*^i and r_a^i were recalculated with consideration of atmospheric stability, represented in Fig. 2 by the symbol Φ. In the final calculation of the fluxes at each pixel, the latent heat flux (LE^i) was estimated with a micrometeorological aerodynamic equation, in which Δe^i in Fig. 2 represents the difference between the air vapor pressure and the saturation vapor pressure at T_s^i. Net radiation (R_n^i) was estimated from the surface radiation balance, with model-estimated α_i, downwelling longwave irradiance $L^i\downarrow$ from calculations following Satterlund (1979), upwelling irradiance $L^i\uparrow$ based on the surface temperature T_s^i, and the observed $\overline{K}\downarrow$. Sensible heat flux (H^i) was estimated as the residual term in the surface energy balance equation.

3. RESULTS AND DISCUSSION

Figure 3 shows the daytime variations of area-averaged $\overline{Rn}$, $\overline{LE}$, and $\overline{H}$ found with PASS2 for the WRW during CASES-97 intensive observation periods on days 119, 130, and 140 (April 29, May 10, and May 20). The maximum $\overline{Rn}$ value was larger by 100 W m^{-2} on May 20 than on April 29, while the maximum $\overline{LE}$ value increased by 350 W m^{-2} and maximum $\overline{H}$ decreased by 100 W m^{-2}. The increases in $\overline{Rn}$ for this series of cloudless days were driven mostly by changes in solar irradiance, but $\overline{LE}$ and $\overline{H}$ clearly responded to changes in soil moisture from rainfall.

Figure 4 shows the spatial distribution in the WRW of cumulative water loss, computed from the modeled evapotranspiration rates during the daytime hours on the three days of intensive operations. The changes in daily water loss correspond to variations in $\overline{LE}$ shown in Fig. 3 and reflect changes in estimates of soil moisture content (Song et al., 1999). On day 119, the evident patchiness of water loss in the WRW corresponds to variations in soil moisture content. The water loss from the grasslands in the eastern half of the WRW on day 130 (May 10) appears to be smaller than the loss from the western portion, where agricultural row crops are more common. The greater slopes and relatively thin soils in the grasslands probably contributed to greater runoff during rainfall events, leaving less soil moisture.

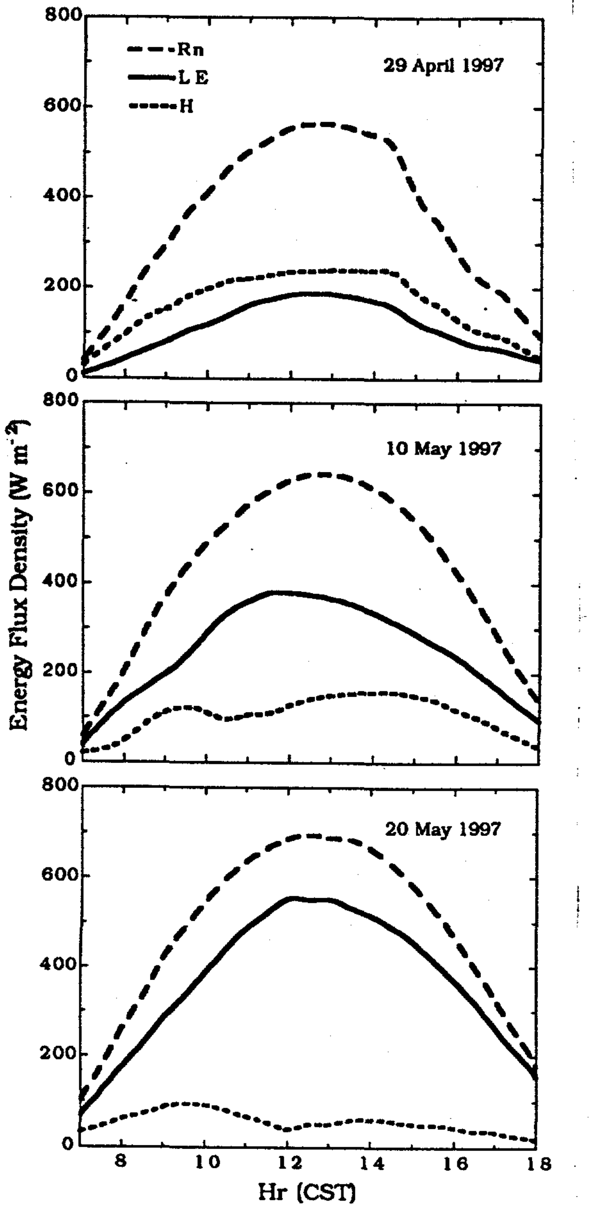

Fig. 3. Modeled daytime net radiation (Rn), latent heat flux (LE), and sensible heat flux (H), averaged over the Walnut River Watershed.

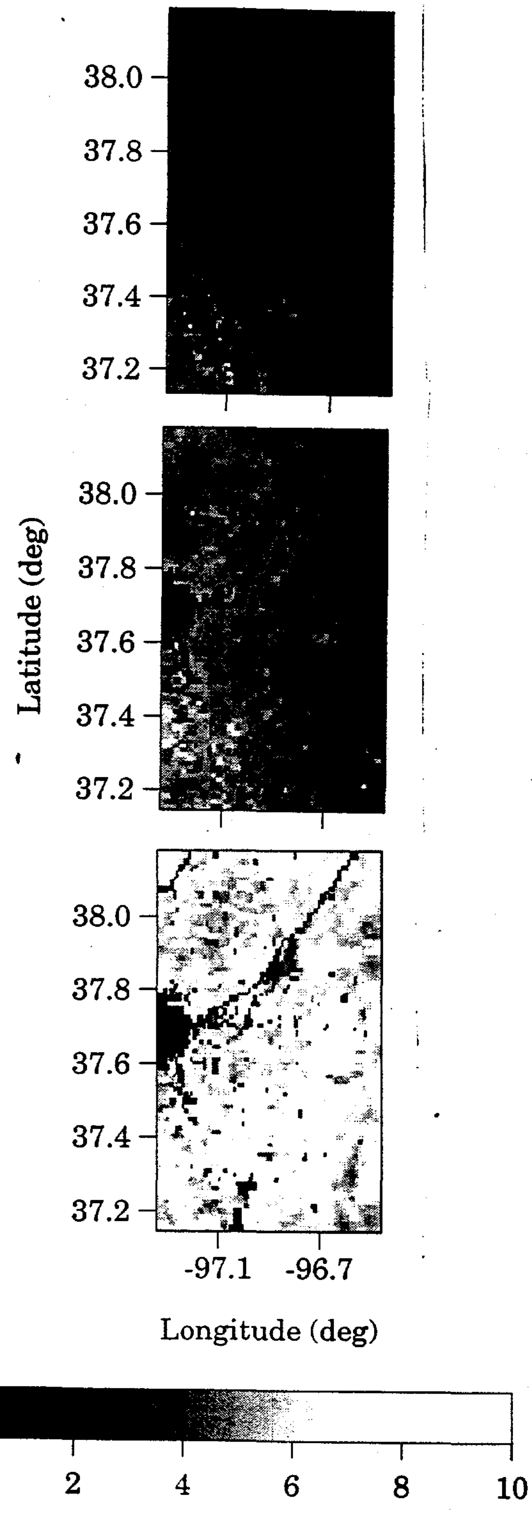

Fig. 4. Distribution of modeled water loss (mm day^{-1}) during the daytime in the Walnut River Watershed and immediate surrounding areas on (top to bottom) days 119 (April 19), 130 (May 10), and 140 (May 20) in 1997.

High rates of evapotranspiration occurred on day 140 (May 20), shortly after a substantial rainfall throughout the region. In all cases, low evapotranspiration rates occurred in urban areas and at roadways (e.g., in Wichita, located in Fig. 4 on the western edge of the area mapped).

4. CONCLUSIONS

The PASS2 model provides an efficient method to calculate diurnal evapotranspiration rates and energy fluxes at scales of individual pixels (1 km by 1 km in this study) of satellite data. Inputs to PASS2 include data on NDVI values for the most recent clear day, diurnal surface meteorological conditions, and extractable soil moisture. Estimates of extractable soil moisture can be provided by PASS1 with clear-day satellite data and short-term surface meteorological observation. In future work, soil moisture reductions due to evapotranspiration will be incorporated into PASS2 so that evapotranspiration can be simulated on a continuous basis. Further evaluation of PASS2 results will be accomplished in part by comparison of the modeled evapotranspiration rates to those measured at several surface sites in the WRW during CASES-97.

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