**Long-Term Evapotranspiration Estimates in the Walnut River Watershed in
Kansas***

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This project focuses on improving and testing a simple method for using reflectance data obtained from satellites to infer the effects on evapotranspiration of variations in soil moisture availability. The major advantage to the method, which is based on the parameterization of subgrid-scale surface fluxes (PASS) model (Gao 1995; Gao et al. 1998), is that it can be applied to areas having diverse surface characteristics where direct surface flux measurements either do not exist or are not feasible and where meteorological data are available from only a limited number of ground stations. The emphasis of the PASS model is on improving (1) methods for using high-resolution satellite remote sensing data to derive the essential parameters for individual types of surfaces over large areas, (2) algorithms for describing the interactions of near-surface atmospheric conditions with surface processes, and (3) algorithms for computing surface energy and water vapor flux at a scale close to the size of a satellite pixel.

An operational modeling system is being developed. Testing of the system is accomplished by applying it to the Walnut River Watershed (WRW), an instrumented watershed of moderate area (5,000 km²) located just east of Wichita, Kansas. Data from field experiments such as the intensive field campaign in 1997 by the Cooperative Atmosphere-Surface Exchange Study (CASES) and from routine operation of the Atmospheric Boundary Layer Experiments (ABLE) in the WRW are used to evaluate the ability of the PASS model to estimate accumulated water loss over a growing season.

The research goals of the project are as follow:

1. Improve the existing satellite-data interfacing modules, especially the parameterization of soil moisture availability and water vapor flux.
2. Apply and evaluate the methods by using measurements at ground stations distributed within the WRW.
3. Develop an operational version of the modeling system, and apply it to derive long-term evapotranspiration estimates at the WRW.

Progress during Year 1

The original PASS model was modified, refined, and separated into two parts (Song et al. 1999a, 1999b). PASS1 is limited to inferring conditions near the times of satellite overpasses and focuses on inferring the root-zone available moisture (RAM) content. PASS2 carries the simulation forward in time and focuses on estimating evapotranspiration throughout the diurnal cycle. Observations made during the 1997 CASES study at the ABLE site (LeMone et al. 1999) were used to implement and evaluate both parts of PASS (Fig. 1).

As in previous versions of PASS, model inputs for PASS1 consist of standard surface meteorological observations, solar insolation data, and estimates of the normalized difference vegetation index (NDVI) and thermal infrared temperature derived from 1-km-resolution remote sensing data from the advanced very-high-resolution radiometers aboard the National Oceanic and Atmospheric Administration polar-orbiting satellites. Modeled values of RAM content (θ_r) for the WRW agreed fairly well with observations during CASES-97. For example, the pattern in θ_r matched raingauge-corrected radar observations of previous rainfall events (Fig. 2). These comparisons were limited to fairly moist conditions and to areas typical of the Great Plains. PASS1 uses more physically realistic distribution functions for wind speed and ambient water vapor content than were used previously by PASS. With reliable radiosonde data and local estimates of visibility, LOWTRAN7 appeared to make adequate atmospheric adjustments of the satellite-derived reflectances to produce surface values.

PASS1 incorporates a linear relationship between RAM content and the extraction factor that relates evapotranspiration rate without moisture stress to the rate with moisture stress. The linear function might be less satisfactory than a nonlinear relationship for individual sites with extensive soil characterization, but the linear relationship in PASS1 appears to produce more realistic spatial variations in soil moisture content. Furthermore, the linear relationship can be used with databases derived from soil surveys that estimate available water capacity; information on field capacity and wilting point water contents are not as readily available and are not needed for use of the linear relationship.

PASS2 focuses on long-term estimates of evapotranspiration over extended areas and uses PASS1 outputs for the times of selected satellite overpasses. PASS2 attempts to account explicitly for the effects of albedo, roughness length, ground heat flux, wind speed, air temperature, and air vapor pressure for each pixel, but it requires surface observational data from only a limited number of standard meteorological stations. PASS2 uses the same land use, soil available water capacity, and NDVI data as does PASS1, as well as many of the same algorithms. The surface temperature for each pixel and time increment is computed in PASS2 with an approximation involving the surface energy budget. After application of the distribution functions, evapotranspiration rates are computed via a bulk aerodynamic formulation, which is possible because soil moisture and thus surface water vapor conductance were evaluated for preceding time steps in the model. Estimating evapotranspiration is less susceptible to the cumulative effects of errors in the energy balance than in the PASS1 procedure of finding evapotranspiration as a residual term in the energy budget.

Figure 3 shows the averages of latent heat fluxes measured by the National Center for Atmospheric Research (NCAR) during CASES-97, along with the averages of latent heat fluxes modeled by PASS2 for the nearest pixels. The fluxes were measured by eddy correlation at a height of about 3 m; the effective surface "footprint" for the fluxes extended to about 300 m upwind. Both modeled and measured latent heat flux (λE) values were relatively small for the sequence of days starting on day of year (DOY) 119 (April 29), moderately large for the sequence starting on DOY 130 (May 10), and large for the sequence starting on DOY 140 (May 30). This variation from sequence to sequence corresponded well with rainfall and soil moisture patterns; solar irradiance amounts and their diurnal variations changed very little from sequence to sequence for the days with cloudless conditions.

Figure 3 also shows the ranges of λE values across the eight sites at noon, when the ranges were near their maximum values. The ranges were larger for the measurements than for the model results, possibly because of the smoothing effects of the limited spatial resolution of the NDVI data; individual agricultural fields were small in comparison to the resolution of the NDVI data used. For observed λE , the values for a site with mostly bare soil were consistently the smallest. Comparisons with in situ measurements of soil moisture content showed that PASS2 tended to overestimate the rate of depletion of soil moisture content for fields of bare soil and to underestimate depletion rates for winter wheat fields in the springtime. For surface sites in rangeland, which were usually surrounded by grassy fields with similar vegetative characteristics, the model-derived estimates agreed quite well with the locally observed values. Comparisons of PASS2 evapotranspiration results with aircraft-based measurements made during CASES-97 indicated that model-derived estimates over distances of tens of kilometers were, on average, without significant bias.

Figure 4 shows images of a primary type of data product that can be derived from PASS2 outputs: cumulative water loss by evapotranspiration over the region of interest. The individual pixels are 200 m by 200 m in these images but the 1-km resolution in the NDVI data lessens contrasts over distances of up to 2 km.

Research plans for Year 2

Manuscripts on PASS1 and PASS2 results from the first year of study will be completed and submitted to a peer-reviewed journal. Publication will facilitate exploration of the potential of PASS1 to provide initialization and assimilation data on soil moisture content for weather forecast models, which is a desirable feature because dense networks of soil moisture measurement stations are generally not available as a data source.

Future work will include development of methods for obtaining continuous estimates of evapotranspiration with PASS2, which requires precipitation estimates for each model pixel. Radar data products available from the Arkansas-Red Basin River Forecast Center will be acquired and adapted for this purpose. Because the spatial resolution of these radar data is not as good as the resolution of the satellite-derived data used in PASS, the contrast in modeled evapotranspiration rates among the satellite pixels will be lessened.

Algorithms in PASS1 and PASS2 will continue to be examined and refined. For example, soil moisture available for evapotranspiration is estimated in the current version of PASS2 by tabulating the amount of moisture in a single layer of soil with limited depth, and the influence of soil moisture on evaporation rates is described with a factor that is linearly related to the ratio of available soil moisture content to the soil moisture capacity. Slightly more sophisticated schemes will be considered, such as a description using a deeper soil column with several layers, from which moisture extraction rates and availability for evapotranspiration are assumed to vary with depth. Using such a scheme might improve soil moisture estimates for dry conditions, when plant roots usually extract a greater proportion of water for evapotranspiration from relatively large depths than during wet conditions. The WRW is currently being instrumented at several locations to measure profiles of moisture content, which will allow some testing of such alternative methods of describing soil moisture variations with PASS2. An extensive array of soil profile measurements has been installed near the site at Whitewater (Fig. 1), and an energy balance Bowen ratio station will be installed there to measure evapotranspiration.

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Figures

Fig. 1. Outline of the Walnut River Watershed and locations of selected observational sites during CASES-97. The lightly shaded area to the east denotes mostly rangeland and grassland. The remaining area is primarily cropland. The primary sources of data for PASS1 and PASS2 on local surface meteorological conditions, evapotranspiration rates, and soil moisture content were obtained at the eight stations operated by NCAR.

Fig. 2. Estimates of available soil moisture (left) from PASS1 and precipitation amounts (right) derived from measurements with an S-band polarized radar system operated by NCAR at a location east of the WRW.

Fig. 3. Latent heat fluxes λE from PASS2, averaged among the eight pixels closest to the eight NCAR sites, and the average λE observed at the sites. The vertical bars represent the maximum range of values for the eight pixels or eight sites.

Fig. 4. Examples of the spatial distributions of daily evapotranspiration rates estimated by using PASS2.

- Argonne remote sensing sites (RSSs)
- NCAR sites
- Argonne surface flux site

DOY 119

DOY 130

DOY 140

DOY 122

DOYs 127-128

DOYs 138-139

Fig. 3