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MODELING EVAPOTRANSPIRATION IN A SUB-TROPICAL CLIMATE

M. R. Savabi[1]
T. A Cochrane[1]
E. German[2]
C. Ikiz[1]
N. Cockshutt[1]

[1]U.S. Department of Agriculture-ARS
Subtropical Horticulture Research Station
Miami, FL, USA
[2]U.S. Geological Survey
Orlando, FL, USA

Evapotranspiration (ET) loss is estimated at about 80-85% of annual precipitation in South Florida. Accurate prediction of ET is important during and beyond the implementation of the Comprehensive Everglades Restoration Plan (CERP). In the USDA's Everglades Agro-Hydrology Model (EAHM) the soil water intake is linked with the soil water redistribution, soil evaporation, plant transpiration, subsurface lateral flow and subsurface drainage to calculate daily root zone soil water content. Hydrometeorological data from three sites with different soil moisture content and vegetal cover were used to evaluate the EAHM ET routine. In general, the EAHM water balance sub-model simulated the daily ET with acceptable accuracy in the area with standing water (Everglades) while using the Penman method. However, in the area with grass cover, there was a discrepancy between the model simulated and measured ET using either the Penman or the Priestley-Taylor method. The results indicated that in the region with two distinct climate patterns: dry (low humidity, more wind, and less precipitation) and wet (high humidity, less wind and more rainfall) such as South Florida, a combination method like Penman should be used for prediction of daily ET. However, in order to improve the predictability of the ET methods, information about surface albedo is needed for land surfaces with grass vegetation during the growing season.

INTRODUCTION

Evapotranspiration loss is a significant aspect of the water balance in South Florida. It has been estimated that about 80-85% of rainfall (about 140 cm), evaporates back to the atmosphere German (2000). The Comprehensive Everglades Restoration Project (CERP) is designed to allocate more water for restoring the Everglades National Park and to supply the growing demands of South Florida's population and agriculture. In order to allocate the available water resources most efficiently, accurate estimates of ET losses are essential.

There have been several modeling approaches to predict ET processes on a watershed scale; Ritchie (1972) Shuttleworth and Wallace (1985), and Sumner (1996). These models varied in their complexity and incorporate various physical processes. However, each allows for the integration of physical and biological factors to simulate ET over a variety of surface conditions. For the USDA's Everglades Agro Hydrology Model, EAHM (Savabi and Shinde, 2003) and USDA's Water Erosion Prediction Project (WEPP) model (USDA, 1995), Ritchie's approach (Ritchie, 1972) has been selected. Ritchie's method uses readily available climate and vegetation data and has been tested over a range of conditions (Arnold and Williams, 1985; Pochop et al., 1985; Savabi et al., 2001). Several scientists examined use of the modified Priestley-Taylor equation by varying the coefficient α for soil moisture availability (Davis and Allen, 1972), solar radiation (De Bruin, 1983), and the combination effect of solar radiation, vapor pressure deficit, soil moisture and seasonal factors such as plant cover.

Albedo is an important factor in improving the prediction of ET using models that rely on solar radiation as input data. Albedo is a difficult value to quantify because it varies with vegetative cover, wetness, and other factors such as solar wavelength. Wet surfaces, for example, have a lower albedo than dry surfaces, but also vary with turbidity. Similarly, multiple reflections and absorptions always reduce the albedo of deep vegetation (Miller, 1955). Satterlund (1969) suggests that visual estimation of albedo can be misleading as the human eye is only sensitive to about 50% of the solar spectrum reaching the earth. Therefore it is important to measure or estimate albedo taking into account the actual conditions of the field or region and better yet to utilize appropriate instrumentation for such purpose. Albedo is typically defined as the fraction of solar energy (shortwave radiation) reflected from the Earth back into space. The value of albedo ranges from 0 to 1, where 0 is a black, perfectly absorbing, surface and 1 is a white, perfectly reflecting, surface. In the EAHM and WEPP models, solar radiation is used as an input to the model and net solar radiation is calculated using the albedo factor. Therefore, the determination of an accurate albedo is important in estimating ET using both the Penman (1963) and the Priestley-Taylor methods. Currently the EAHM model varies albedo between a fixed value of soil albedo and a fixed value of vegetation albedo (set to 0.23). Therefore in typical simulations, when soil albedo is set at 0.23, the albedo remains constant throughout the year. It was therefore hypothesized that a seasonal value or function should be used to simulate the albedo. This seasonal change of albedo should be applied to reflect both vegetation cover and standing water. The objective of this study was to evaluate the evapotranspiration prediction of the USDA-Everglades Agro-Hydrology model that uses the Penman and Priestley-Taylor equations on the natural grass and the Everglades National park site with standing water.

MATERIALS AND METHODS

Climatic data from three energy-balance Bowen ratio sites were used to compare evapotranspiration simulated by the EAHM to actual subtropical climate conditions. The available measured climatic parameters at these stations were wind speed, wind direction, relative humidity, temperature, precipitation, solar radiation, net radiation, and various other specific parameters used to measure actual ET using the Bowen ratio energy balance method (Bowen, 1926).

$$Rn - G - W = A = H + \lambda E \tag{1}$$

where, Rn is net radiation, (W m^{-2}), G is soil heat flux (W m^{-2}), W is the amount of heat related to change in temperature of water standing on the land surface (for cases in the Everglades), H is the sensible heat flux (heat transported by convection), and λE is the latent heat flux (heat related to vaporization or condensation of water). Rn, G, and W are measured directly by the instrumentation and thus A, which represents the total amount of energy available for sensible and latent heat transport can be determined. Calculations of λE and H are accomplished by using the Bowen ratio (Bowen, 1926) and the following relation:

$$\lambda E = (A)/(1 + B) \tag{2}$$

where B is the Bowen ratio, or ratio of H to λE. The Bowen ratio, as calculated from the equipment, is derived from temperature and vapor pressure measurements at two heights (2 m) above a crop canopy or soil surface:

$$\beta = \gamma \frac{K_h}{K_v} \frac{\Delta T}{\Delta e} \tag{3}$$

where K_h and K_v are the eddy transfer coefficients for sensible and latent heat respectively; ΔT and Δe are the differences in temperature in ^0C and vapor pressure in kPa over the same elevation difference. In practice K_h is assumed equal to K_v and therefore,

$$\beta = \gamma \frac{\Delta T}{\Delta e} \tag{4}$$

where, γ, the psychrometric constant, is a function of temperature, atmospheric temperature and specific heat of air at constant pressure. Combining equations 1 through 4 will result in:

$$\lambda E = \frac{Rn - G}{1 + \gamma \frac{\Delta t}{\Delta e}} \tag{5}$$

where ΔE is the latent heat of vaporization of water (which is a function of temperature) (W m^{-2}) Rn is net radiation, (W m^{-2}), G is soil heat flux (W m^{-2}), γ is psychrometric constant (KPa C^{-1}), and $\Delta t/\Delta e$ is air temperature (^{o}C) and vapor pressure differences (K Pa) measured at two heights above the canopy, respectively.

The ET rate can be computed from calculated latent heat flux using the relation:

$$ET = a \cdot \left(\frac{\lambda E}{\lambda} \right) \tag{6}$$

where a is a conversion constant and λ is the latent heat of vaporization of water (which is a function of temperature).

Three representative data sets from different locations in southern Florida were used in this study (Figure 1). The first data set of actual ET using Bowen ratio measurements was obtained from a climatic station denominated as "Site #7" which is located in the Everglades National Park at coordinates 25º 36' 55'' latitude and 080º 42' 11'' longitude (Figure 2). This climatic station is maintained by the United States Geological Survey (German, 2000) and is specifically located over permanently wet terrain with sparse saw grass vegetation. Consistent data were available from 01/01/1999 to 10/16/2000 at 15 minute measured intervals which was converted to daily values for modeling purposes.

The second data set was obtained from a climatic station in the Everglades designated "Site #8". This site is located in the Everglades and for over half of the year it has water standing, but from about February to June the surface is dry and vegetation is prominent. ET data for this site was available from 01/01/1999 to 10/16/2000 at 15 minute intervals, which for modeling purposes was converted to daily values. The third data set was obtained from climatic measurements at the United State Department of Agriculture, Miami, Florida. This site is designated as "Station" and is located on typical agricultural lands of southern Florida with permanent grass cover vegetation under and around the climatic measuring station. Continuous data from 1/1/1999 to 8/12/2000 at 20 minutes were available and were converted to daily values for the modeling.

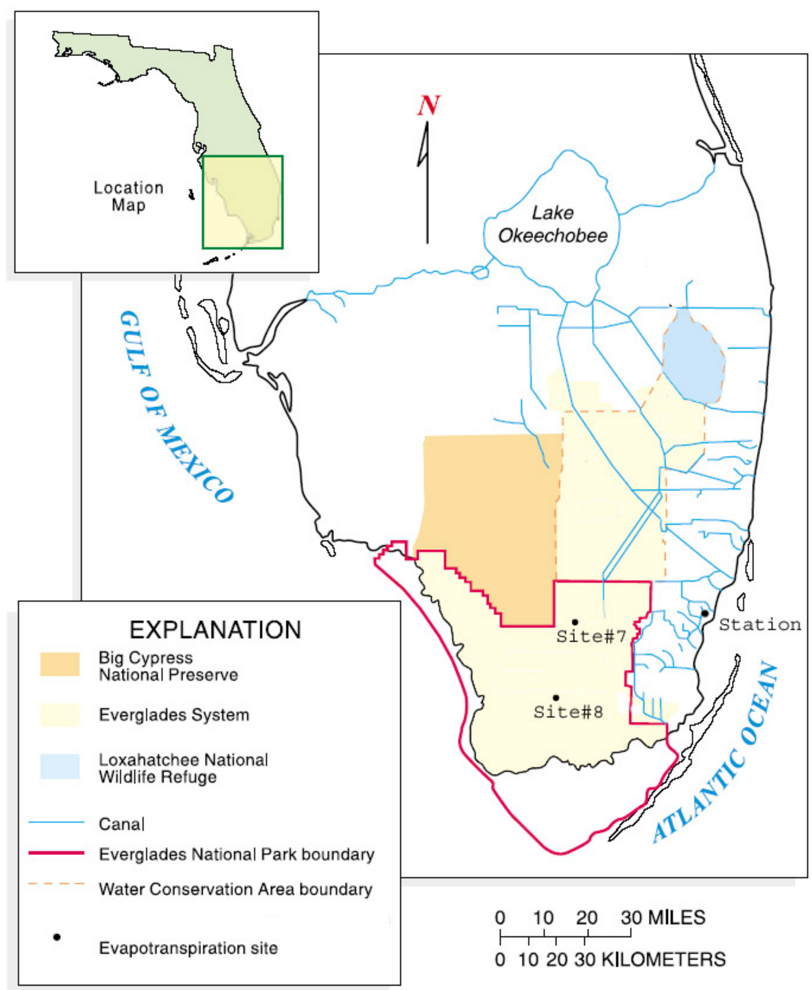


Figure 1: Location of ET measuring instrumentation in south Florida.

Figure 2. Energy balance Bowen ratio in the Everglades National Park (Site 7) and the USDA in Miami Station.

Actual ET values derived from data obtained by the climatic station using the energy balance Bowen method have been compared to simulations with the Penman and Priestley-Taylor methods as used in the EAHM for both Site #7 and the Station. Continuous wet terrain throughout the year under Site #7 provides ET values which can be used to evaluate the performance of each method in calculating potential ET. Actual ET values from the Station provide a means to evaluate the performance of each method under typical agricultural conditions (grass cover). The Penman method is the default model for calculating ET in the EAHM. It takes into account daily radiation, temperature, wind speed, and dew point temperature (relative humidity). The basic equation for the Penman method is the following:

$$Eu = \frac{\Delta}{\Delta + \gamma}(Rmj - G) + \frac{\gamma}{\gamma + \Delta}6.43(1.0 + 0.53u_z)(e_z^o - e_z) \tag{7}$$

where *Eu* is the latent heat of evaporation (MJ m^{-2} d^{-1}), *Rmj* is the net solar radiation (MJ m^{-2} d^{-1}), *G* is soil heat flux (MJ m^{-2} d^{-1}), and Δ is the slope of the saturated vapor pressure at mean air temperature, u_z is wind speed (m s-1), and e_z is saturated vapor pressure (KPa).

The Priestley-Taylor method is an alternative method of calculating ET in the EAHM when only solar radiation, average temperature, and surface albedo are available as input data.

$$Eu = 1.26\frac{Rl}{53.3}\frac{\Delta}{\Delta + .68} \tag{8}$$

where, *Rl* is daily net solar radiation in Langley per day.

The MOD43B3 Albedo Product (MODIS/Terra Albedo 16-Day L3 Global 1km SIN Grid) from the NASA Earth Observing Satellites was used to determine seasonality of albedo (Schaaf et al., 2002). This product provides both the white-sky albedos and the black-sky albedo values (at local solar noon) for MODIS bands 1-7 (Table 1) as well as for three broad bands (0.3-0.7μm, 0.7-5.0μm, and 0.3-5.0μm). The total energy reflected by the earth's surface in the shortwave domain is characterized by the shortwave (0.3-5.0μm) broadband albedo, however, the visible (0.3-0.7μm) and near-infrared (0.7-5.0μm) broadband albedos are often also of interest due to the marked difference of the reflectance of vegetation in these two spectral regions.

Goodness of Fit Test

Comparisons between actual measured ET values and model predicted values were conducted using the Nash-Sutcliffe coefficient (*NS*) (Nash-Sutcliffe, 1970), and the coefficient of variation. The Nash-Sutcliffe coefficient is recommended by the ASCE for modeling comparisons. *NS* values closer to 1 are considered to be a better fit between predicted and observed values, whereas coefficient of variation values closer to 0 are considered a better fit. *NS* is calculated as follows:

$$NS = 1 - \left[\frac{\sum_{i=1}^{n} (M_i - P_i)^2}{\sum_{i=1}^{n} (M_i - P_i)^2} \right] \tag{9}$$

where, *M* are the measured values, *P* are predicted values, and *n* is equal the number of events simulated.

The Coefficient of variation is also used for comparison of predicted and actual measurements and is calculated as follows:

$$CV = \frac{\left(\frac{1}{n} \cdot \sum_{i=1}^{n} (M_i - P_i)^2 \right)^{0.5}}{\sum_{i=1}^{n} \left(\frac{M_i}{n} \right)} \tag{10}$$

RESULTS AND DISCUSSION

Comparison of ET Methods

Comparison of the model simulated and measured ET for Site 7 and the Station were conducted in this study. Site 8 climate data was used only for determining the accuracy of the measurements. Comparisons between the model simulations using Priestley-Taylor and Penman equations and measured ET are shown in Figures 3 and 4. The results indicate that the Penman method, which is

Table 1. MODIS instrument bands 1 to 7.

BAND #	RANGE nm reflected	KEY USE
1	620-670	Absolute Land Cover Transformation, Vegetation Chlorophyll
2	841-876	Cloud Amount, Vegetation Land Cover Transformation
3	459-479	Soil/Vegetation Differences
4	545-565	Green Vegetation
5	1230-1250	Leaf/Canopy Differences
6	1628-1652	Snow/Cloud Differences
7	2105-2155	Cloud Properties, Land Properties

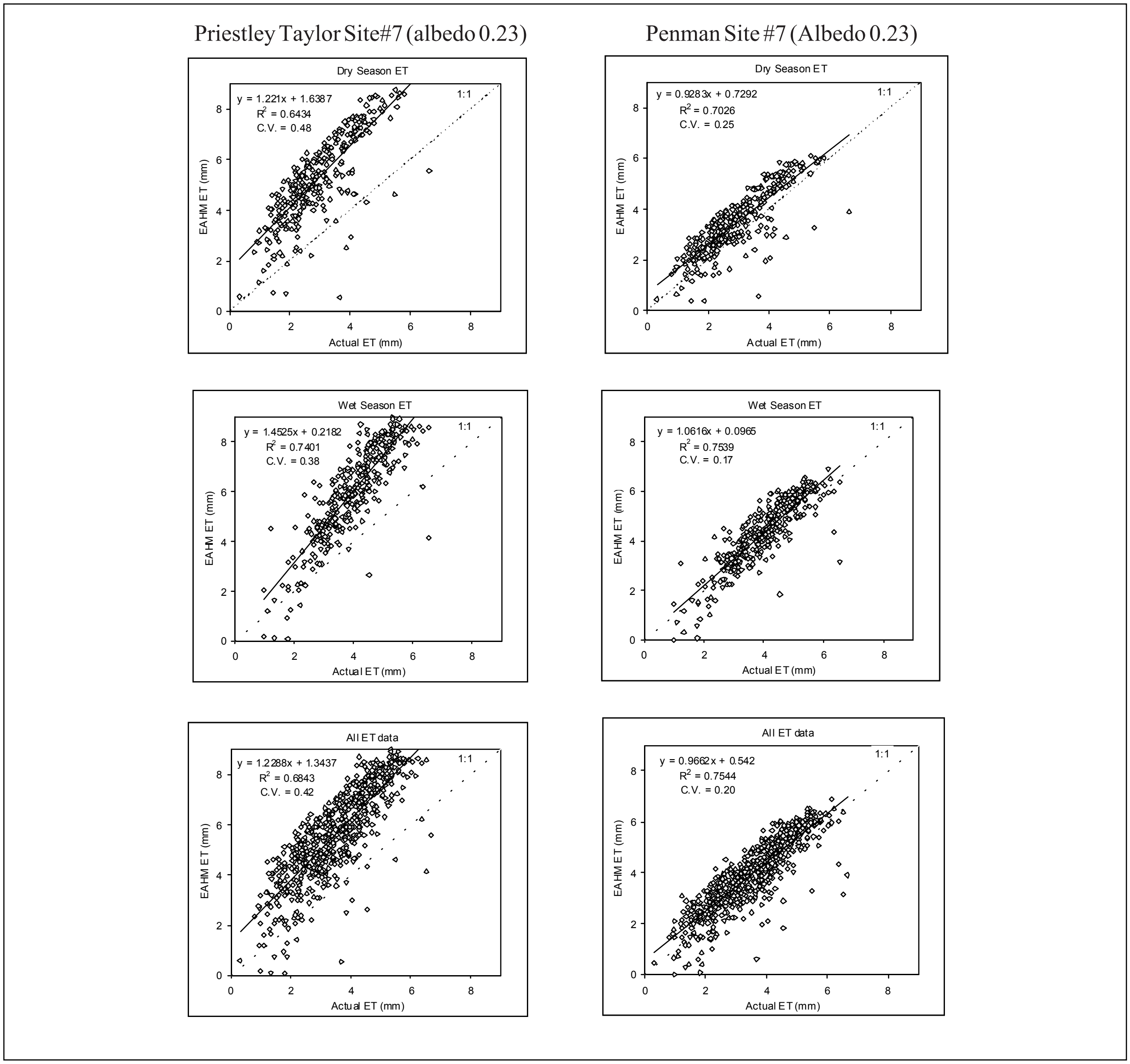


Figure 3: Comparison between Priestley-Taylor method and Penman method for simulations of Site #7 using albedo of 0.23.

used as the default ET prediction method in the EAHM, is a better predictor of daily ET than the Priestley-Taylor method for both Site #7 and the Station (grass cover). These figures also show the comparisons of daily ET during the wet and dry seasons at both sites. The wet season is between May 1st to October 31st as suggested by the climatic patterns of southern Florida. Predicted values using both the Penman method and the Priestley-Taylor method were obtained using a constant albedo of 0.23. It should be noted that the rainfall data for the Station from Julian days 225 to 290 in 1999 was replaced with precipitation data from Site #7 due to missing rainfall data (equipment malfunction). Regression coefficients and coefficients of variation show that the Penman method performs better in the wet and dry season (Figure 3) at Site 7 and the Station. Similarly, the calculated Nash-Sutcliffe coefficients show the Penman method is a better predictor than the Priestley-Taylor method in either dry or wet seasons. Standard error and coefficient of variation also show that the wet season values are better predicted than the dry season when using a constant Albedo of 0.23 (Table 2).

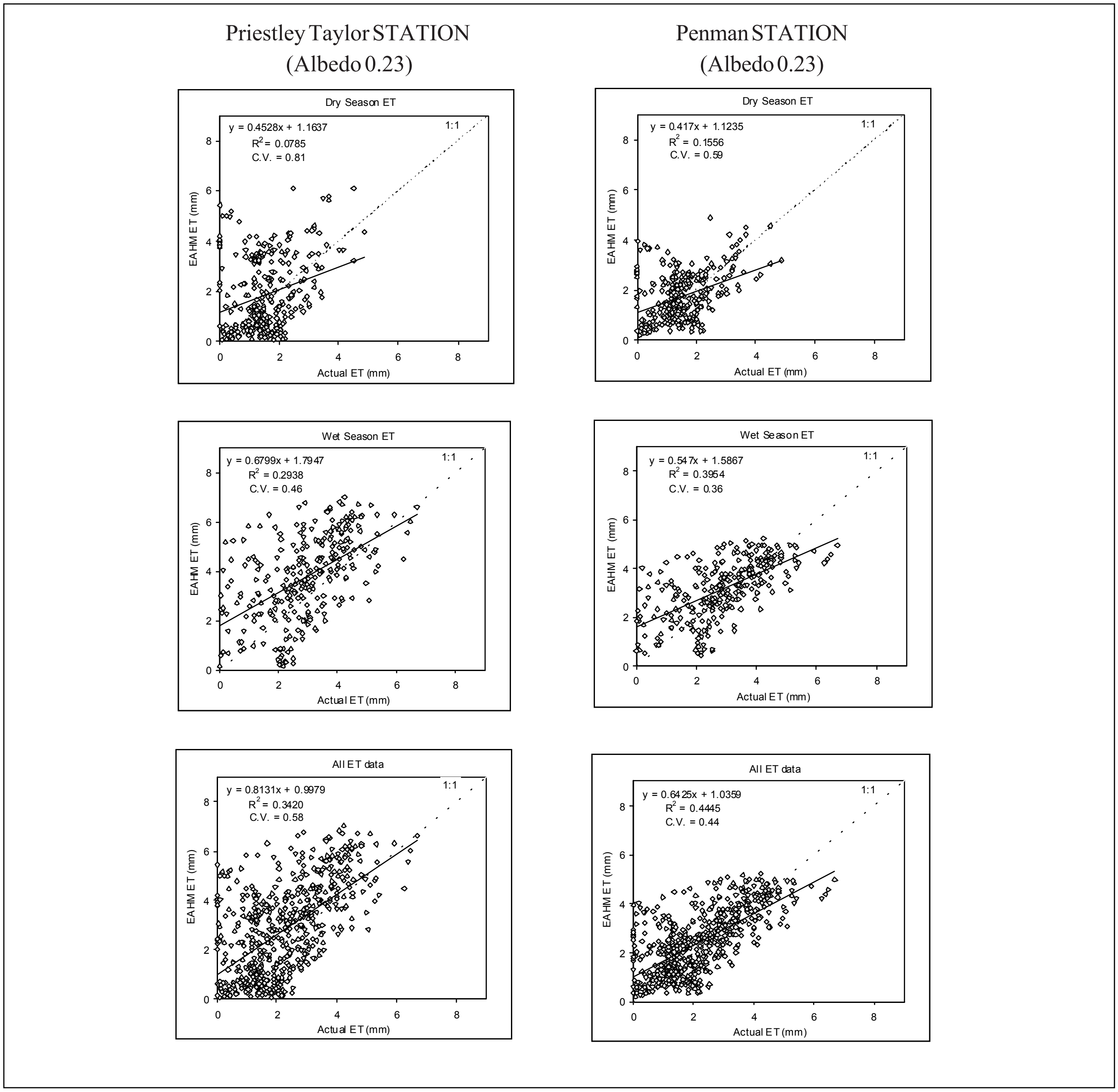


Figure 4. Comparison between Priestley-Taylor method and Penman method for simulations of Station using albedo of 0.23.

In the Priestley-Taylor method the value of α is set to 1.26 (Equation 8) and is assumed to reflect free water surface or a dense, well watered canopy (Priestley and Taylor, 1972). In addition, unlike the Penman method, the seasonal variability of dew point temperatures (Figure 5) and wind velocity (Figure 6) is not considered in the Priestley-Taylor method. Considering the subtropical climate in southern Florida that has two distinct weather patterns; a wet season (lower dew point temperatures and prevailing wind, Figures 5 and 6) and a dry season (higher dew point temperature and more prevailing wind, Figures 5 and 6), can help explain the better performance of the Penman method as compared to the Priestley-Taylor method which does not take into account these factors.

Albedo Factor

Although no instrumentation was placed in the sites to measure albedo directly, previous studies

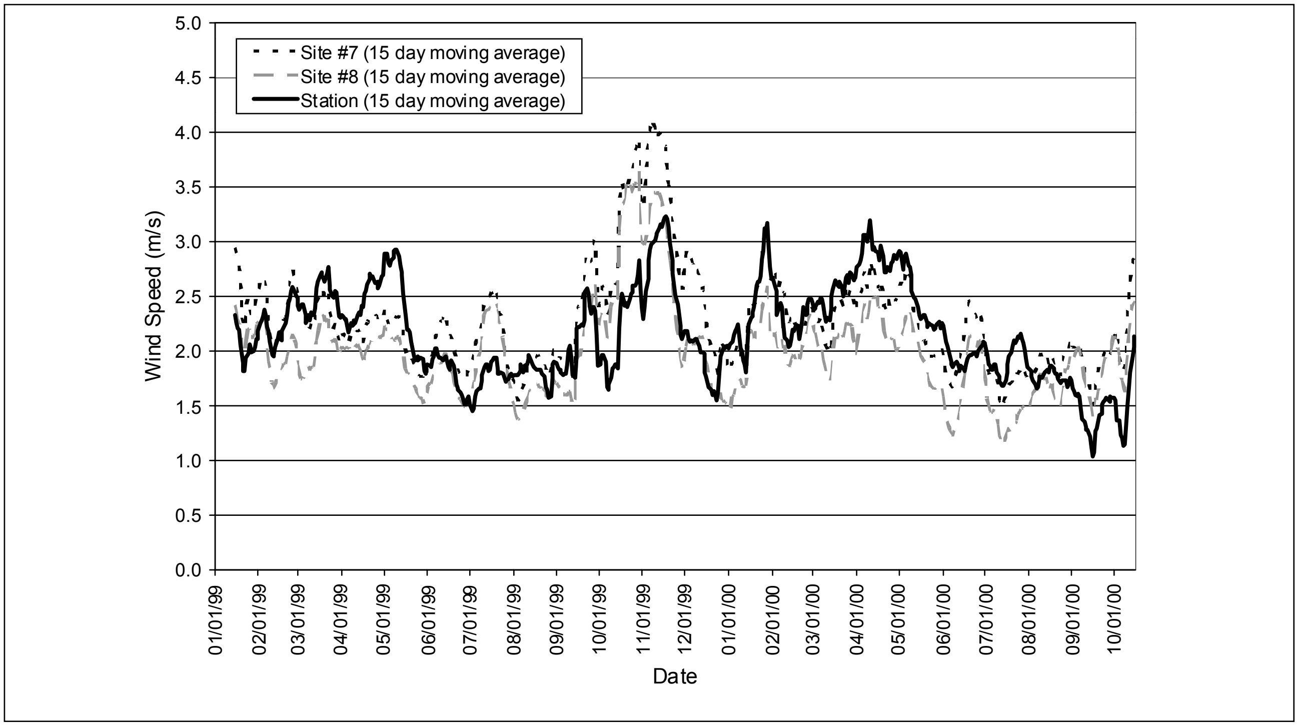


Figure 5. Seasonal variation of wind speed for the three ET measurement sites 7, 8 and Station in southern Florida.

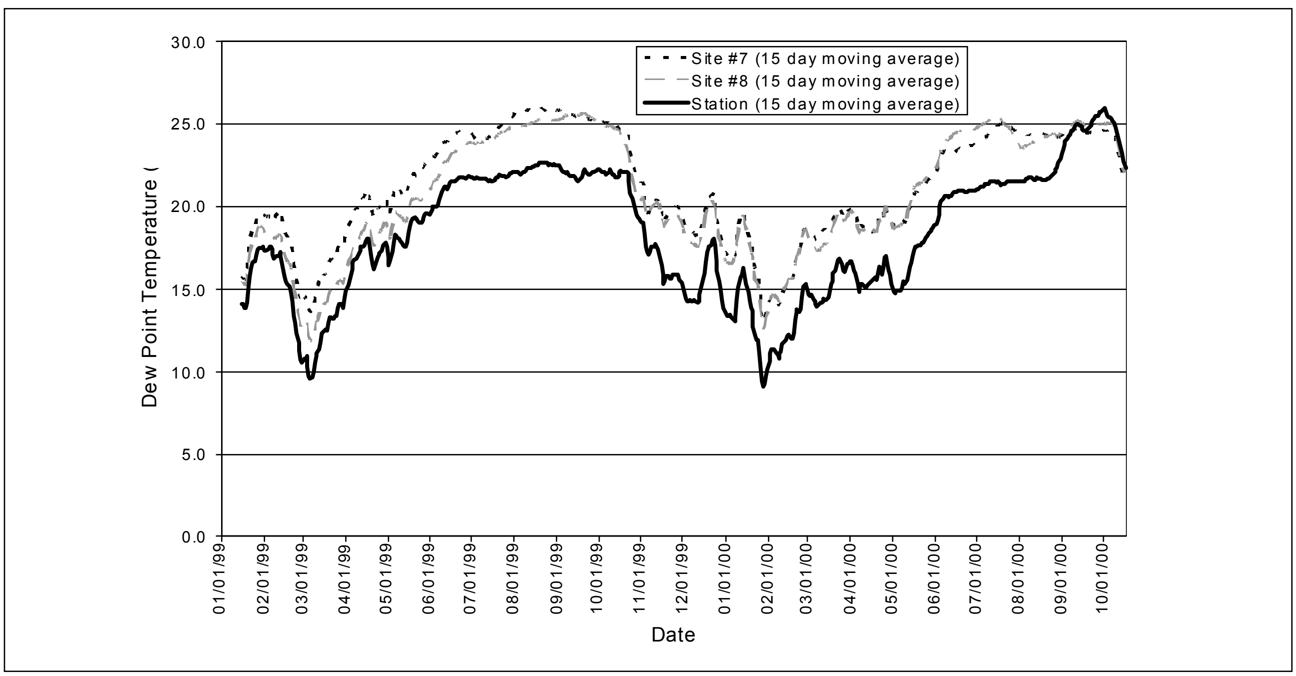


Figure 6: Seasonal variation of dew point temperature for the three ET measurement sites, 7, 8 , and Station in southern Florida.

as well as satellite imagery was used to determine appropriate albedo values and to determine a possible seasonal variation. Albedo for small agricultural watershed surfaces for shortwave radiation is recommended by Satterlund (1969) to vary from 0.25 to 0.35 for short green dry grass, and vary from 0.15 to 0.20 for wet green grass. Most modeling of ET, including the currently EAHM and WEPP model uses a standard recommended value of 0.23 for all crops and is not corrected to seasonal variations of vegetation cover.

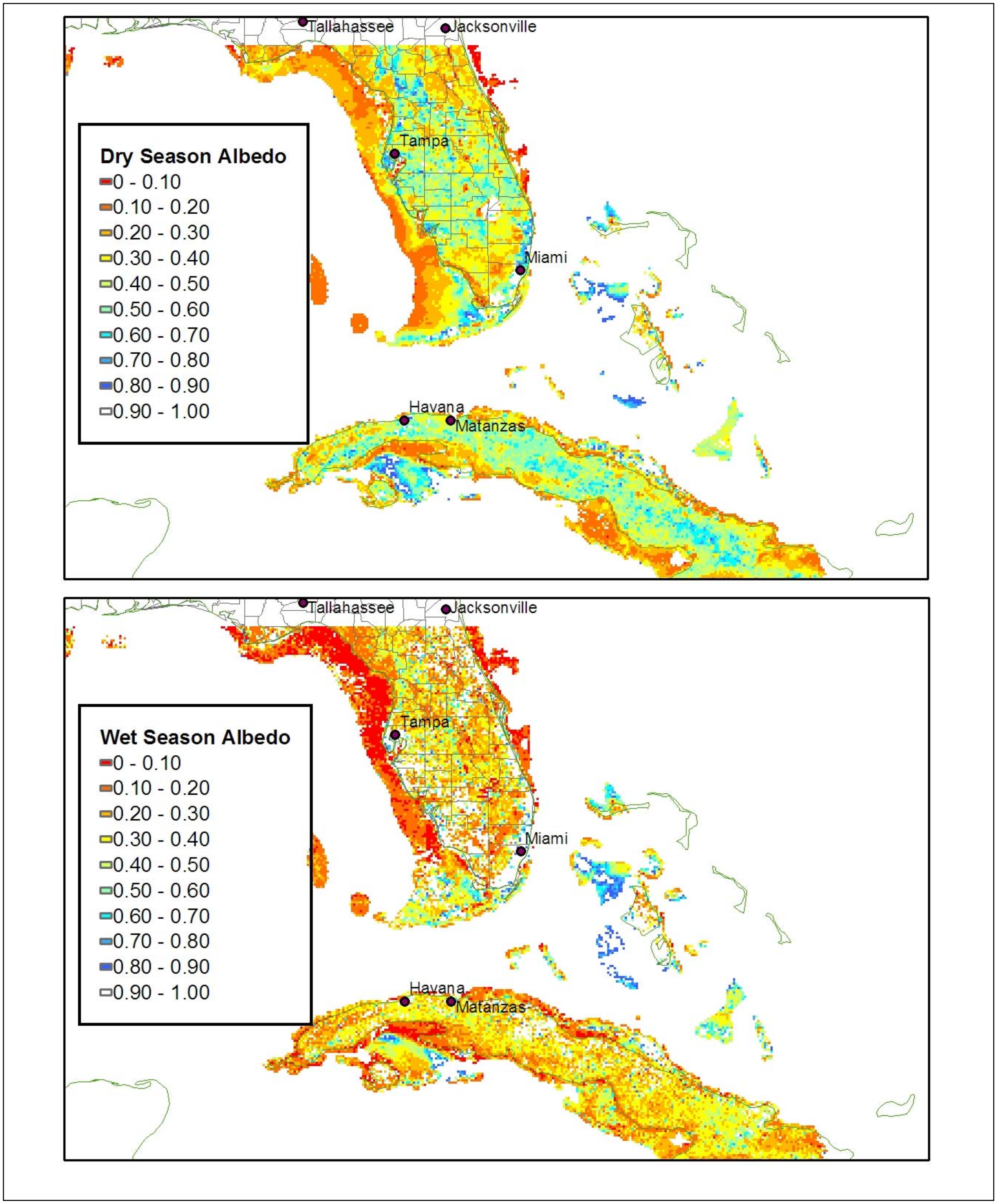


Figure 7. (a) Wet season (16 day average from day 209) and (b) Dry season (16 day average from day 97) visible wavelength albedo (0.3-0.7um wavelength).

Research using satellite imagery clearly shows a seasonal dependence of albedo (Figure 7). In this case the MODIS instrument, from NASA's earth observing satellites, is used to determine large area albedo of southern Florida. The images are of average albedo for a 16 day period starting at Julian day 209 representing the wet season and for a 16 day period starting at day 97 representing the dry season. Albedo values range from 0 to 1. Values greater than 0.50 represent for the most part cloud cover or bad data. During the summer months (wet season) albedo is shown to be a lower value, whereas during the winter months (dry season) albedo is significantly higher if one excludes values greater than 0.5 which as mentioned before are possibly due to cloud cover. Satellite measured albedo shows a difference between albedo for wet and dry seasons.

For small scale modeling, however, actual values of albedo as measured by satellites, may not be representative of the actual values for the field. Measurements such as the ones obtained by MODIS encompass an average value for a large area (which may include water, clouds, or multiple other surfaces) because the resolution of the measurements is low (500 by 500 m). Similarly, it can be argued that albedo from a single leaf varies significantly from that of a whole tree. Although the seasonal tendency is consistent, the actual measurements of albedo from space may be different than the actual measured field conditions.

However, accurate estimate of the albedo value is important in prediction of ET using the hydrologic model that uses radiation to predict ET. Sensitivity of the EAHM in simulation of daily ET to the albedo value is provided in Figure 8. While keeping all the input parameters the same, the annual ET will increase by 14% as the albedo increases from 0.1 to 0.35 (Figure 8). We observed that the daily values of ET where over predicted with both the Penman and the Priestley-Taylor methods for simulations using albedo of 0.23 as shown in Figures 3 and 4. Figure 9 shows accumulative ET values for both 1999 and 2000 using the Penman method with different albedo values. The model over predicts ET while using albedo of 0.23, under predicts while using albedo of 0.35, and a better fit for the case when albedo was varied during the year at Site 7.

We used standard field albedo values of 0.23 for the wet season and a theoretical 0.35 for the dry season. Changing the albedo to a higher value such as 0.35 under predicts ET in many cases. Using a seasonal dependent albedo of 0.23 during the wet season and 0.35 during the dry part of the year improves the results significantly, particularly for Site #7 (Table 2). As shown in Figure 10, using the Penman equation with seasonally variable albedo will result in less discrepancy between the measured and predicted daily ET.

Recovering Lost Data

The energy balance Bowen ratio instrumentation for the measurement of ET is a delicate instrument and can easily be prone to data loss. The two main measurements are Δt and Δe, (Equation 5). We used a criterion recommended by Ohmura (1982) to reject the ET data for early morning, late afternoon and during precipitation. In addition, some data were lost by instruments not functioning as result of tampering by birds, blockage of vapor pressure gauges by insects, normal use and wear, disruptions such as strong storms and other factors. If any one of these instruments fails, or provides bad data, the Bowen ratio and therefore ET can not be computed. To salvage the data that were lost, the Bowen ratio has to be estimated empirically. A function was derived using multiple linear regression to estimate the Bowen ratio based on air temperature, relative humidity, solar radiation, and wind velocity. Measured data from 1999 were used as a basis to derive this function.

$$BR = -0.0629*AT + 0.0141*RH + 1.9225*SR + 0.1147*WS \qquad (11)$$

where, BR is the Bowen ratio, AT is the air temperature in degrees Celsius, RH is the relative humidity (%), SR is the solar radiation (MJ/m^2) and WS is the wind speed in MPH. Comparisons between actual measurements of the Bowen ratio and fitted values using the above function for

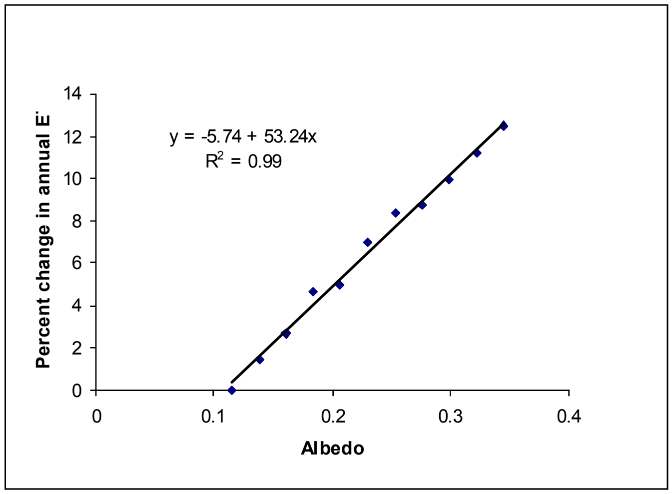
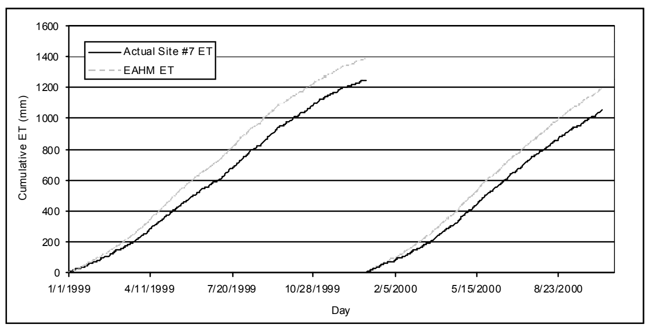
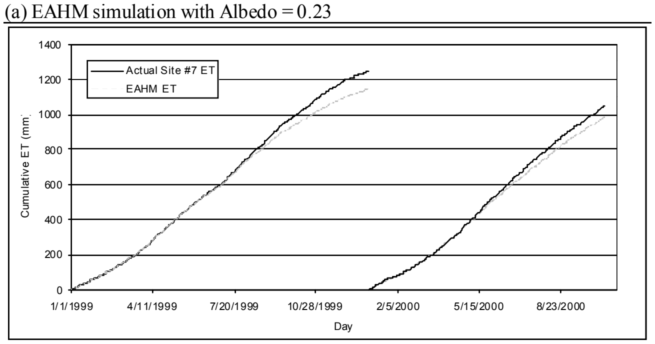


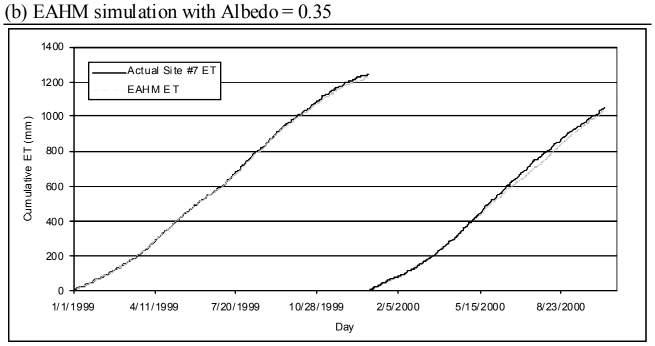
Figure 8. Sensitivity of the ET calculation by EAHM using Penman method to varying albedo values.



(a) EAHM simulation with Albedo = 0.23



(b) EAHM simulation with Albedo = 0.35



(c) EAHM simulation with seasonal Albedo (0.35 and 0.23)

Figure 9. Comparison between accumulated measured and simulated ET using Penman method at Site #7 while using different albedo values during 1999 and 2000.

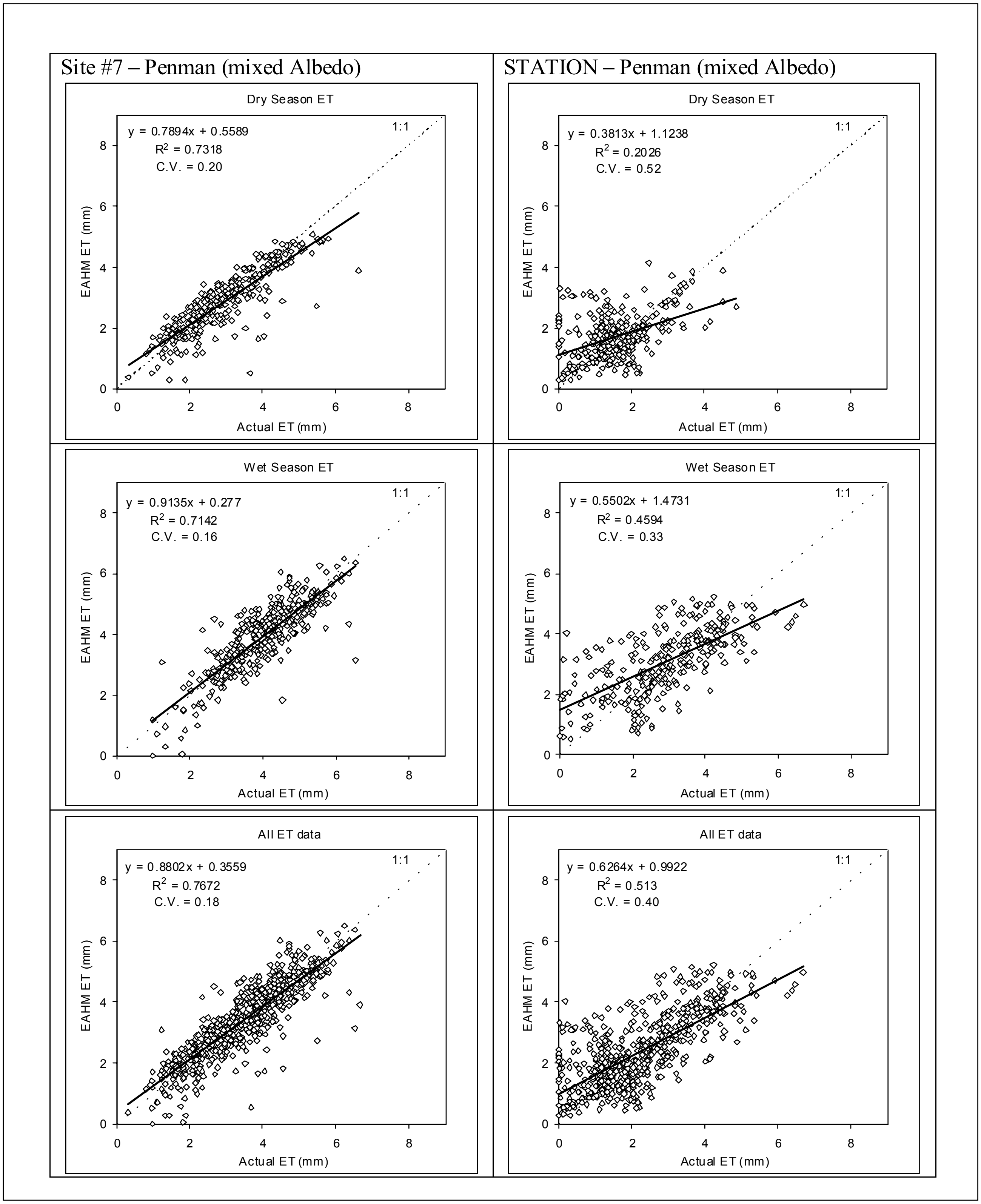


Figure 10. Comparison between measured and simulated ET using the Penman method during the dry, wet and entire year in Site #7 and Station using different albedo values during 1999 and 2000.

years 1999 and 2000 results in a *NS* value of 0.67 which represents a good fit. Comparisons of ET predictions compared to measured values with estimated (fitted) Bowen ratios for years 2001, 2002, and 2003 for the agricultural station are shown in Table 3.

Table 3. EAHM model ET predictions compared to measured values with estimated (fitted) Bowen ratios for years 2001, 2002 and 2003.

Location	Model	Albedo	Days	Mean ET (mm)			SE (mm)			CV			NS
				total	dry	wet	total	dry	wet	total	dry	wet	total
station 2003	Penman	0.23	365	813	295	518	0.77	0.80	0.74	0.35	0.49	0.26	0.20
station 2003	Penman	0.35	365	789	288	501	0.77	0.78	0.76	0.36	0.49	0.28	0.20
station 2003	P+T	0.23	365	993	342	651	1.32	1.22	1.41	0.49	0.65	0.40	-1.35
station 2003	P+T	0.35	365	963	334	630	1.26	1.17	1.35	0.48	0.64	0.39	-1.15
station 2003	Measured (BR fit)			897	354	544							
station 2002	Penman	0.23	267	576	220	356	0.94	1.05	1.15	0.44	0.57	0.47	-0.62
station 2002	Penman	0.35	267	563	217	346	0.93	1.01	1.15	0.44	0.56	0.49	-0.58
station 2002	P+T	0.23	267	664	224	440	1.29	1.53	1.50	0.52	0.82	0.50	-2.05
station 2002	P+T	0.35	267	649	221	428	1.25	1.48	1.46	0.52	0.80	0.50	-1.87
station 2002	Measured (BR fit)			693	274	419							
station 2001	Penman	0.23	275	582	170	412	0.82	0.43	1.15	0.39	0.26	0.48	0.08
station 2001	Penman	0.35	275	582	181	401	0.83	0.46	1.17	0.52	0.46	0.53	0.05
station 2001	P+T	0.23	275	739	218	521	1.22	0.82	1.67	0.46	0.40	0.55	-1.04
station 2001	P+T	0.35	275	721	214	506	1.18	0.77	1.61	0.60	0.65	0.59	-0.90
station 2001	Measured (BR fit)			684	196	489							

SUMMARY AND CONCLUSIONS

Evapotranspiration (ET) loss is estimated at about 80-85% of annual precipitation in south Florida. Accurate prediction of ET is important during and beyond the implementation of the Comprehensive Everglades Restoration Plan (CERP). In the USDA's Everglades Agro-Hydrology Model (EAHM) the soil water intake is linked with the soil water redistribution, soil evaporation, plant transpiration, subsurface lateral flow and subsurface drainage to calculate daily root zone soil water content. Hydrometeorological data from three sites with different soil and vegetal cover were used to evaluate the EAHM ET routine. In general, the EAHM water balance sub-model simulated the daily ET with acceptable accuracy in the area with standing water (Everglades) while using the Penman equation. However, in the area with grass cover, there was a discrepancy between the model simulated and measured ET using either the Penman or Priestley-Taylor method. The results indicate that for an area with two distinct climate pattern of dry (low humidity, more wind, less precipitation) and wet (high humidity, less wind and more rainfall) such as south Florida, a combination method such as the Penman should be used for prediction daily ET. Albedo is an important parameter that should be varied seasonally to improve the predictions of ET using the EAHM. Using values of 0.23 for the wet season and 0.35 for the dry season improved the results significantly, which suggests that vegetation albedo should be a function of the actual plants cover and the season (time varying). However, more information about the effect of albedo in a land surface with grass vegetation during the growing season could improve model predictions.

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REFERENCES

Arnold, J.G., and J.R. Williams. 1985. Evapotranspiration in a basin scale hydrologic model. In: Advances in Evapotranspiration, Proceedings of the National Conference on Advances, ASAE, St. Joseph, MI 49085, pp.

405-413.

Bowen, I.S. 1926. The ratio of heat losses by conduction and by evaporation from any water surface. Physical Review, 2nd series, v. 27, no. 6, pp. 779-787.

Davis, J.A, and C.D. Allen. 1973. Equilibrium, potential and actual exportation from cropland surface in southern Ontario. J. of applied Meteorology. Vol 12, P 649-657.

De Bruin, H.A R. 1983. A Model for Priestley–Taylor Parameter α : J of Climate and Applied Meteorology v 22, p 572-578.

German, E.R. 2000. Regional evaluation of evapotranspiration in the Everglades. U.S. Geological Survey Water-Resources Investigations Report 00-4217, 48 pp.

Miller, D.H. 1955. Snow cover and climate in Sierra Nevada, California University, Ca. Pub in Geog. 11.218 pp.

Nash, J.E., and J.E. Sutcliffe. 1970. River Flow Forecasting Through Conceptual Models, part 1- A discussion of principles. J. of Hydrology, 10 (3):282-290.

Ohmura, A. 1982. Objective Criteria for Rejecting Data for Bowen Ratio Flux Calculations. J of Applied Meteorology. Volume 21 pp 595-598.

Penman, H.L. 1963 Vegetation and hydrology. Tech. Comm. No. 53, Commonwealth Bureau of Soils, Harpenden, England. 125pp.

Pochop, L.O., F.M. Smith, and R.E. Smith. 1985. In: Advances in Evapotranspiration, Proceedings of the National Conference on Advances in Evapotranspiration, ASAE publication 14-85, St. Joseph, MI 49085, pp. 262-267,.

Priestley, C.H.B., and R.J. Taylor. 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Review, v. 100, pp. 81- 92.

Ritchie, J.T. 1972. A model for predicting evaporation from a row crop with incomplete cover. Water Resource. Res. 8 (5):1204-1213.

Satterland, D.R. 1969. Wildlife watershed management. Library of Congress catalog num.70-190212.

Savabi, M.R. 2001. Determining Soil Water Characteristics for Application of WEPP Model in South Florida. Transactions of the ASAE, Vol 44. 59-70.

Savabi, M.R., and D. Shinde. 2003. USDA - Everglades Agro-Hydrology Computer Model (User Manual, Model Documentation and Applications). USDA-SHRS-ARS. Research Note 1.

Shuttleworth, W.J., and J.S. Wallace. 1985. Evapotranspiration from sparse crops - an energy combination theory. Quart. J. Roy. Met. Soc. 111:839-855.

Schaaf, C.B., F. Gao, A.H. Strahler, W. Lucht, X. Li, T. Tsang, N.C. Strugnell, X. Zhang, Y. Jin, J.-P. Muller, P. Lewis, M. Barnsley, P. Hobson, M. Disney, G. Roberts, M. Dunderdale, C. Doll, R. d'Entremont, B. Hu, S. Liang, and J.L. Privette. 2002. First Operational BRDF, Albedo and Nadir Reflectance Products from MODIS, Remote Sens. Environ., 83, 135-148.

USDA. 1995. Water erosion prediction project: model documentation. USDA-ARS, NSERL, Report No. 10.

ADDRESS FOR CORRESPONDENCE
M.R. Savabi
USDA-ARS
Subtropical Horticulture Research Station
13601 Old Cutler Road
Miami, FL 33158 USA

Email: rsavabi@saa.ars.usda.gov