EVAPOTRANSPIRATION RATES FROM TWO DIFFERENT SAWGRASS COMMUNITIES IN SOUTH FLORIDA DURING DROUGHT CONDITIONS

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Abstract: Evaporation and plant transpiration (ET) are significant components of the water budget in south Florida. Water loss through ET can exceed rainfall during dry years. Recent advances in instrumentation and measurement techniques have made it possible to develop a better understanding of ET processes and to quantify ET rates. ET rates at two sites vegetated primarily by sawgrass, one near Vero Beach in the St. Johns River floodplain and the other in the southern Everglades of Everglades National Park, yield significantly different ET rates during drought conditions.

The site near Vero Beach has dense sawgrass in a thick peat soil. At this site, the ET fraction, which is the ratio of latent heat (the energy equivalent of ET) to the sum of latent heat and sensible heat (convective heat transport), was affected little by the change in water level even when the water level was nearly 3 feet below land surface. The site in Everglades National Park has a relatively sparse rush/sawgrass community in a thin marl soil. At this site, the ET fraction decreased markedly as the water level dropped to about 2 feet below land surface.

The difference in the relation of ET fraction to water level at the two sites probably is due to the different water-transporting and water-retention characteristics of the soils, and possibly to a difference in root depths. The peat soil may be able to provide moisture for ET more readily than the marl soil under drought conditions. Likewise, a deeper root system in the peat soil may enhance ET under drought conditions. Additional research at the two sites to characterize root depths and soil properties, including water-retention capacity, will aid in determining which factors are responsible for the different ET fractions.

INTRODUCTION

The purpose of this paper is to present evapotranspiration (ET) rates and related meteorological data for two ET sites for the year 2000, and to compare the ET rates and seasonal patterns at the two sites. Drought conditions during January through June of 2000 resulted in a wider range in water levels than usual, so that differences in ET that are more highly related to water availability were more apparent.

ET is a major part of the hydrologic cycle in Florida, particularly in South Florida where the water table is near or above the land surface for much of the year. Some years, actual ET rates are nearly the same as potential ET rates, and the total amount of water lost from the land surface annually can exceed rainfall. Knowledge of ET rates and understanding of factors related to fluctuations in ET are crucial for understanding hydrology of the area and for developing management strategies. As stated by Marjory Stoneman Douglas (1947), “it is the subtle ratio between rainfall and evaporation that is the final secret of water in the Glades.”

The U.S. Geological Survey is operating a network of 14 ET sites in Florida to measure actual ET in a variety of vegetative communities and geographic locations. Of these network sites, 8 sites measure ET with eddy-correlation methods (Sumner, 2001) and 6 sites, all within the Florida Everglades, use the Bowen ratio method (German, 2000).

SITE DESCRIPTION

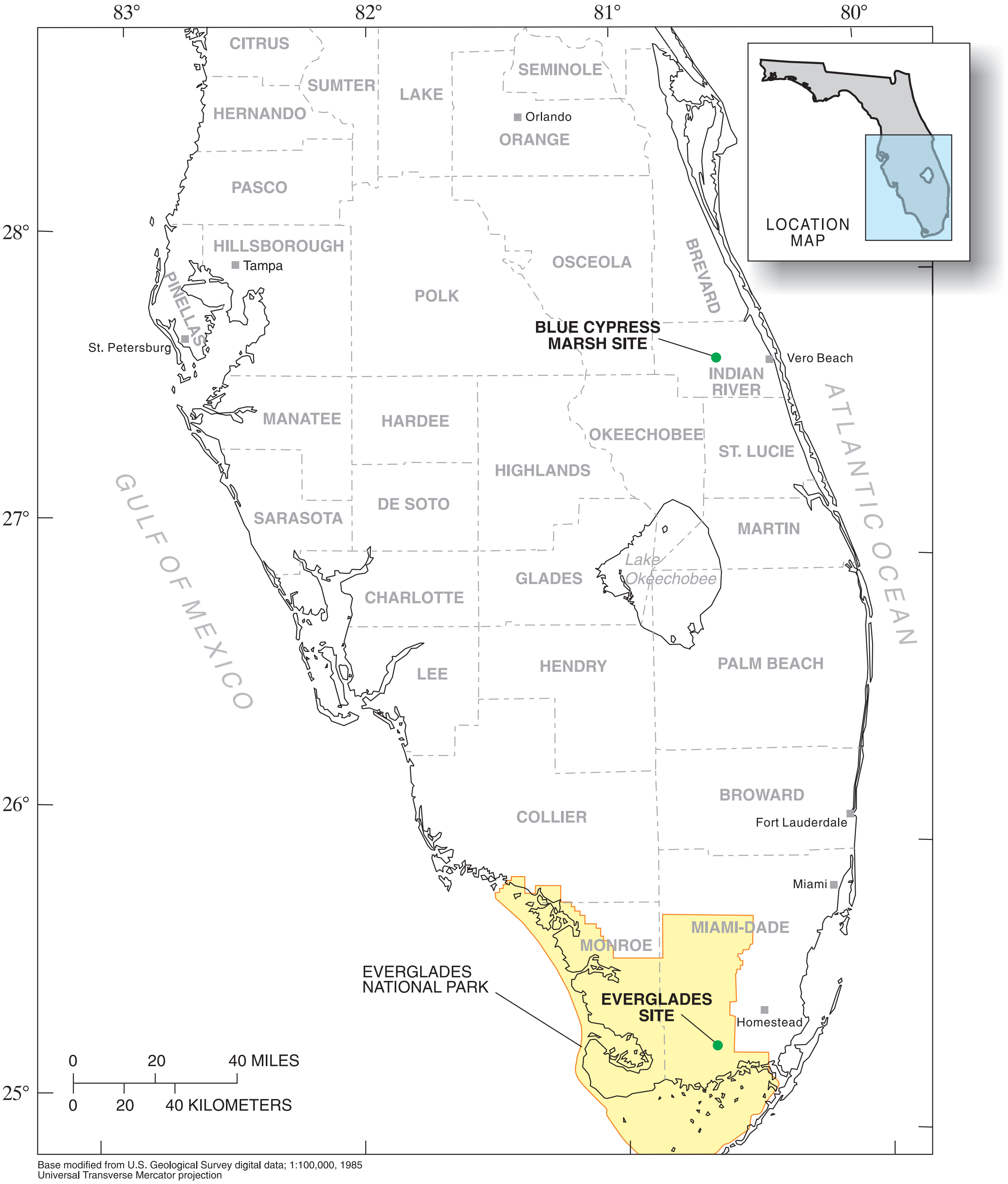
The two sites selected for comparison of ET characteristics have similar climates and hydroperiods but are different with respect to vegetation and soil type. Both sites are in South Florida (figure 1). The Blue Cypress Marsh (BCM) site is located within the headwaters floodplain of the St. Johns River near Vero Beach, Florida (figure 2). This site is characterized by dense, tall (6-7 feet) sawgrass and a thick layer of peat (about 8-9 feet) on limestone bedrock.

The other site is in the Everglades National Park (ENP) southwest of Homestead, Florida (figure 2). The site is characterized by a relatively sparse, short (2-3 feet) mixture of sawgrass and spike rush and a relatively thin marl soil (about 2-3 feet) on limestone bedrock. Periphyton mats are noticeable in open areas between vegetation clumps.

Climatic Characteristics: The climate at both sites is characterized by relatively warm, dry winters and hot, wet summers. More than one-half of the annual rainfall (about 50-55 inches at both sites) generally occurs during June through September, which commonly is referred to as the wet season. Water levels are above land surface several months each year, and generally fall to as much as 2-3 feet below land surface during the dry season each year.

During 2000, daily average air temperatures tended to be higher at the ENP than at the BCM, and the difference generally was greatest in winter (figure 3). Water levels at both sites followed a similar seasonal pattern, but fluctuations were more extreme at the BCM, where the range was from about 2.5 feet below land surface to about 1.1 feet above land surface (figure 4). The water level dropped below land surface late in February at the ENP, but remained above land surface until late April at the BCM. At both sites, water levels did not rise to land surface or above until July, and then remained above land surface until November. The lowest water levels occurred in May at the ENP, and in June at the BCM.

The record of solar intensity, or R_s (incoming short-wavelength solar radiation) for 2000 (figure 5), indicates that both sites are similar in terms of the potential R_s, having daily average R_s values as high as 330 watts per square meter (watts/m^2) in April or May. The R_s varies considerably daily in response to cloud cover, especially during the wet season when thunderstorms are common. The average R_s for 2000 was 207 watts/m^2 at BCM and 206 watts/m^2 at ENP.



Base modified from U.S. Geological Survey digital data; 1:100,000, 1985
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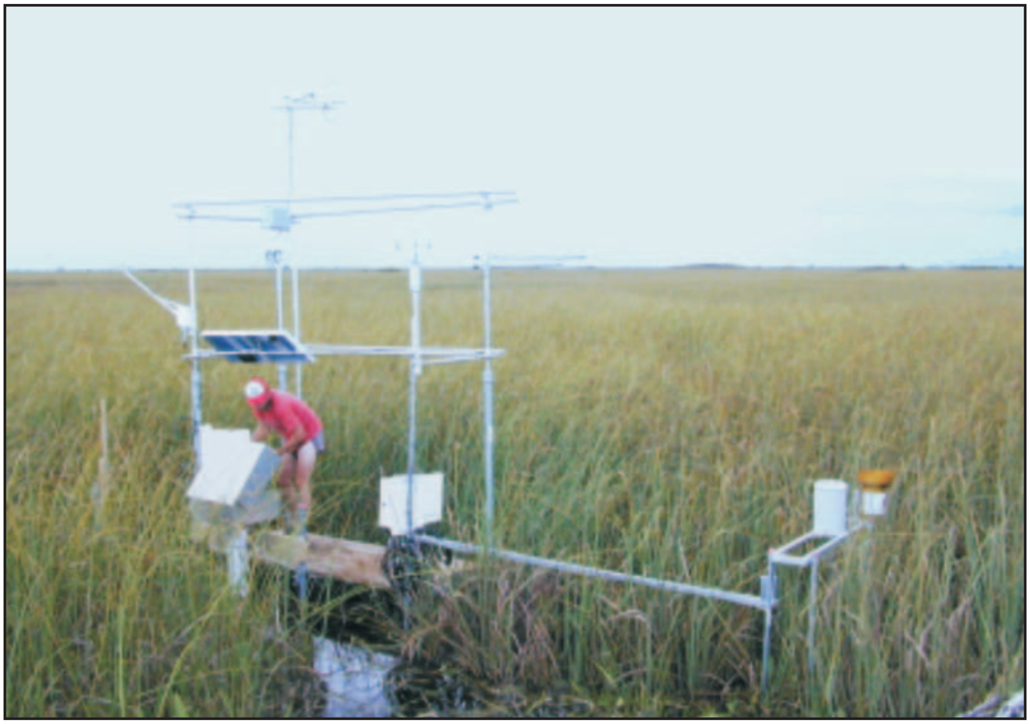
Figure 1. Location of the Blue Cypress Marsh ET site and the Everglades ET site.



Blue Cypress Marsh ET station

Everglades National Park ET station

Figure 2. Evapotranspiration stations in Blue Cypress Marsh and Everglades National Park.

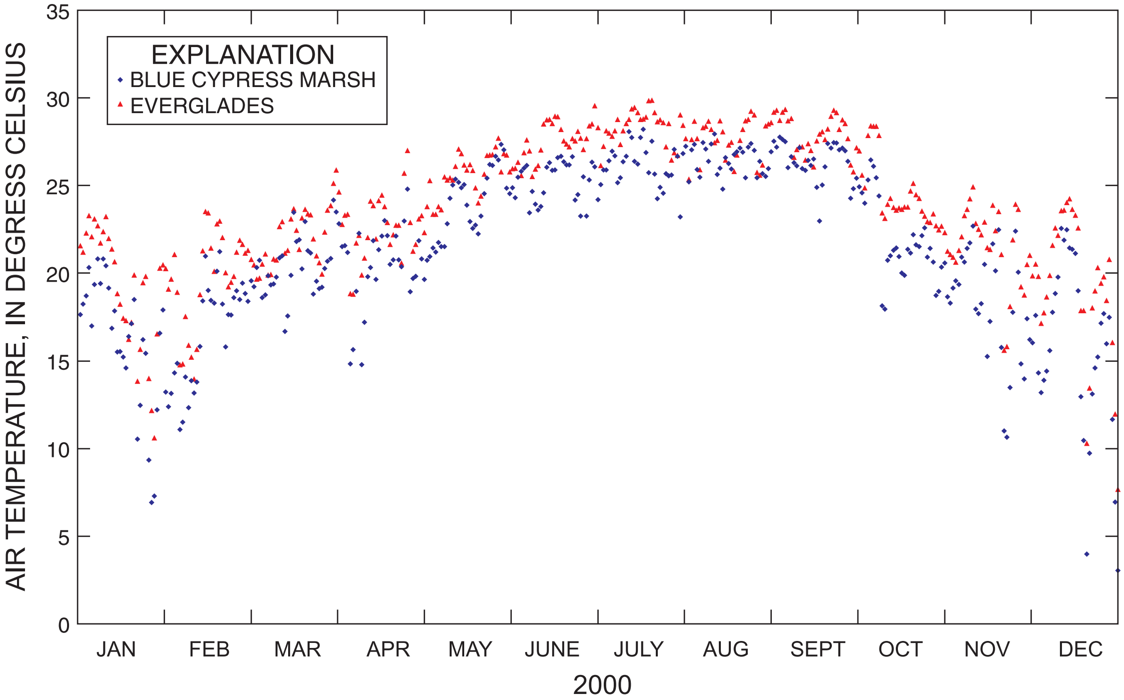


Figure 3. Daily average air temperature, January 2000 through December 2000.

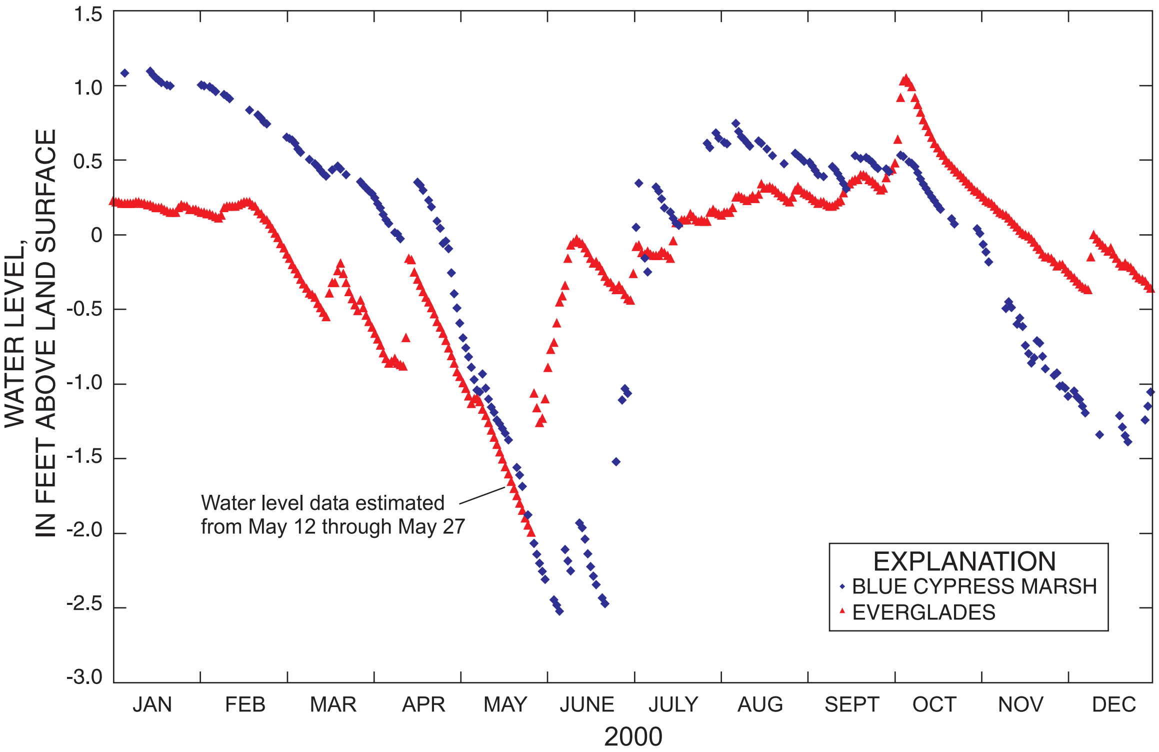


Figure 4. Daily average water level, January 2000 through December 2000.

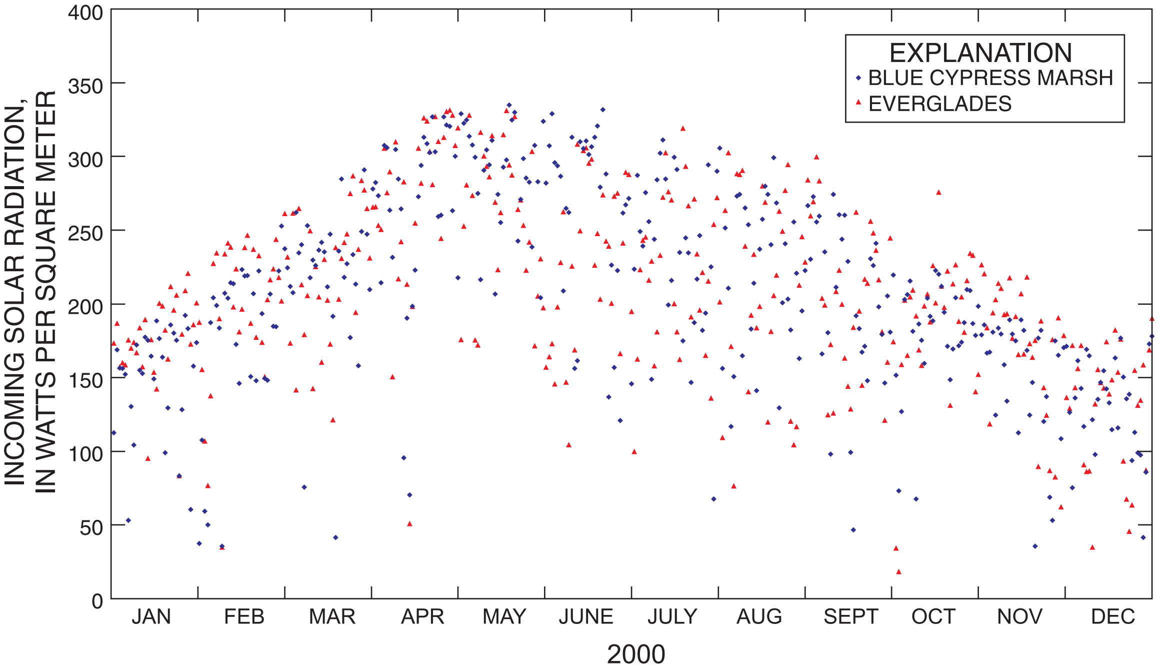


Figure 5. Daily average incoming soar radiation, January 2000 through December 2000.

Instrumentation and Method of ET Measurement: Both sites were instrumented to measure ET using the energy-budget method. The energy budget is given by:

$$R_n - G - W = A = H + \lambda E, \qquad (1)$$

where R_n is the net solar radiation, G is the amount of heat energy passing into the soil, W is the amount of heat related to change in temperature of water standing on the land surface, 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). The left side of equation 1 generally is referred to as available energy (A) and represents the total amount of energy available for combined sensible and latent heat transport. The terms R_n, G, and W are directly measurable, and, thus, A (the sum H plus λE) are readily determined. Individual calculations of λE and H are accomplished by using the Bowen ratio (Bowen, 1926) and the relation:

$$\lambda E = (A)/(1 + B), \qquad (2)$$

where B is the Bowen ratio, or ratio of H to λE. The ET rate, in inches per day, can be computed from the relation:

$$ET = 3.402 \lambda E/\lambda, \qquad (3)$$

where the quantity λE (in watts/m^2) comes from equation 2 and λ is the latent heat of vaporization of water (about 2441 joules/gram at a temperature of 25 degrees Celsius).

The method of Bowen-ratio determination was not the same at both sites. The eddy-correlation method was used to determine daily average B by direct energy flux measurement at the BCM site using a procedure described by Sumner (2001). German (2000) used measurements of air-temperature and vapor-pressure gradients to determine B at 30-minute intervals at the ENP site; German concluded that both methods give comparable measures of B, but have advantages and disadvantages. Two advantages of the eddy-correlation method are that it does not rely on mechanical apparatus and it provides a daily average B, thus, the method is less prone to failure. In contrast, the air-gradient method uses sensors that are relatively low in cost and less likely to be affected or damaged by moisture from rainfall or dew.

Latent heat was determined differently at the two sites. At BCM, a daily average B was computed from the sum of the H and λE for each day. The average A for the day was then used to calculate λE based on the energy budget (equation 2). This approach is necessary because direct measurement of H and λE are biased towards low values during periods of relatively calm wind. However, the bias in both flux terms is the same and the ratio of H to λE is unbiased even during low wind periods.

At ENP, B and A were determined at 30-minute intervals and λE was calculated from equation 2. Daily averages of A and λE were then computed for comparison with values from the BCM.

At both sites, the 30-minute data were screened and models were used to estimate rejected data so that daily values could be computed. At BCM, moisture from rain or dew frequently resulted in unusable data for a portion of many days so that H, λE, and B could not be determined. At ENP, air-temperature and vapor-pressure gradients necessary for determination of B and λE were discarded if the gradients were low in relation to sensor resolution. Additionally, B and λE were not computed if the vapor-pressure gradient indicated that evaporation was not possible even though A indicated that energy was available for ET. The model used to estimate missing λE at BCM was a simple relation between potential ET and λE determined using “good” data (Sumner, 2001). A modified Priestley-Taylor model (Priestley and Taylor, 1972) calibrated using the “good” data (German, 2000) was used to determine λE at ENP.

Comparisons of λE values calculated for the BCM and ENP were restricted to the days when the fill-in models estimated 10 percent or less of the daily λE flux. Using this method, discrepancies resulting from 30-minute estimates between the models were minimized in the comparisons of λE values.

THE RELATION BETWEEN AVAILABLE ENERGY AND SOLAR INTENSITY

A comparison of daily A with R_s indicates that the relation is approximately linear and comparable fractions of incoming radiation were converted to A at both sites (figure 6). This comparison indicates that on an annual basis R_n is approximately the same for a given R_s because the daily G and W in the A term generally are negligible at both sites. This finding is significant because the vegetative cover is much different at the two sites, and indicates that during most of the year the major source of A is affected little by differences in reflected and outgoing long wave radiation between the two types of cover.

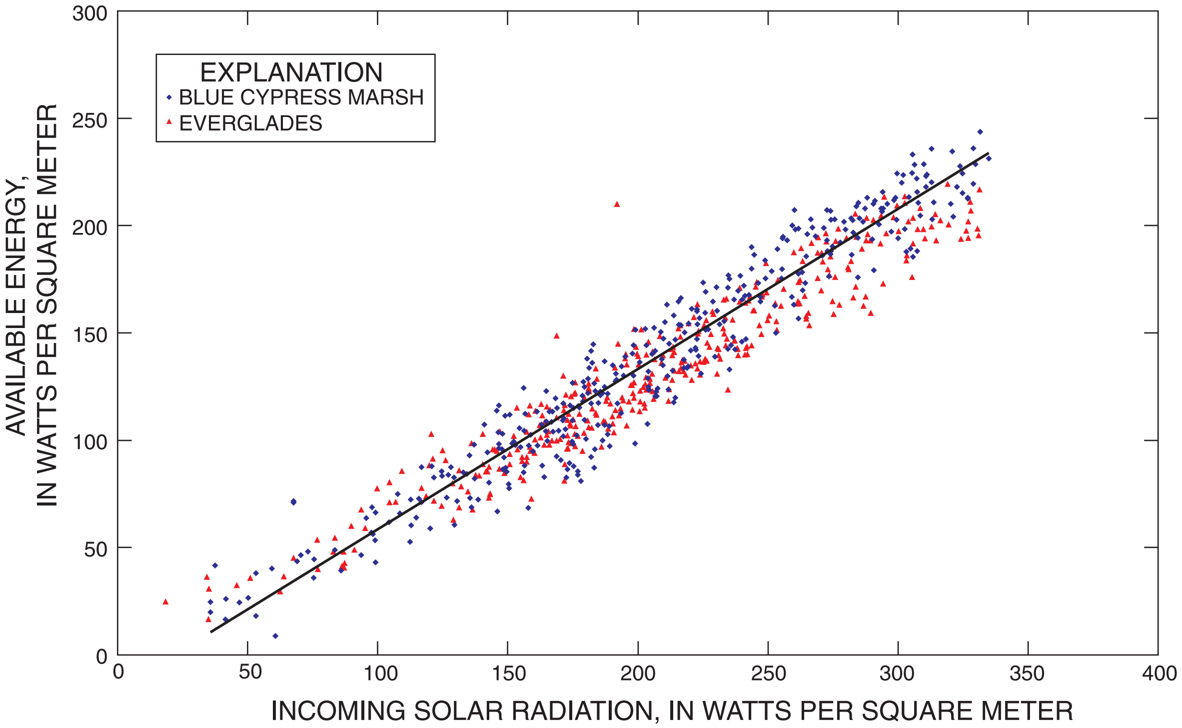


Figure 6. The relation between daily mean available energy and incoming solar radiation (available energy is the sum of latent and sensible heat flux).

The relation between R_s and A is not identical at the two sites over the entire range of R_s. The amount of A tends to be greater at high levels of R_s (greater than about 300 watts/m^2) at the BCM than at the ENP. This could be an indication that at higher solar intensities, surface heating and subsequent outgoing long-wave radiation could be less prevalent at the BCM than at the more sparsely vegetated ENP. Annually, the two sites have similar ratios of A to R_s (0.67 at BCM and 0.64 at ENP).

The ratio of R_s to A indicates a seasonal pattern (figure 7). From mid-May through July, the ratio measured at ENP is almost always lower by 10 percent or more than the ratio measured at BCM. This difference in the ratios occurred during the period of maximum dryness as indicated by the water levels (figure 4), and could be related to differences in albedo (ratio of reflected to incident light) and the relative effects of surface heating at the two sites. During dry periods, the soil at ENP is exposed to direct sunlight, and as a result of reflection and radiation from the ground, A could be reduced. The effect probably is less at BCM (the land surface is dry) because of the thick sawgrass cover that probably has a lower albedo than does soil. During periods when the water level was above the land surface, the ratios of R_s to A appear to be of similar magnitude, although at times there is a significant scatter in the ratios. Thus, a single relation between R_s and A may be applicable for estimation of A for a wide variety of vegetative covers, at least when the land surface is covered by water.

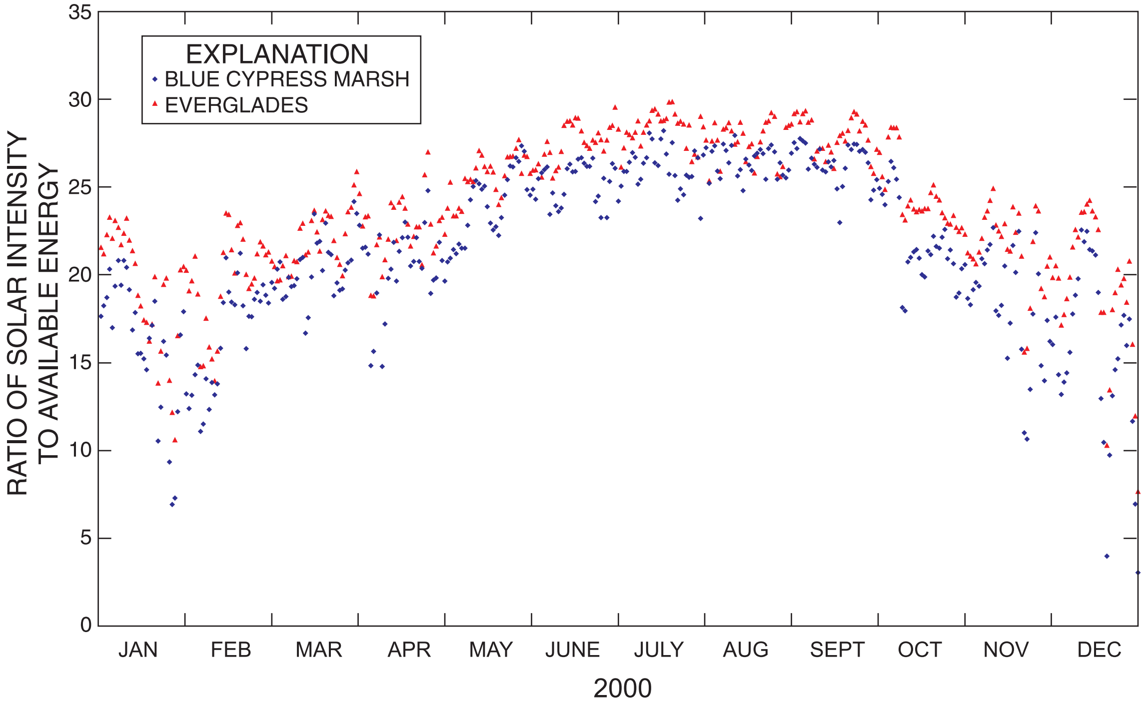


Figure 7. Ratio of solar intensity to available energy, January 2000 through December 2000 (numbers plotted are ratio of daily mean solar intensity to daily mean available energy).

COMPARISON OF EVAPOTRANSPIRATION RATES

The monthly total ET was greater at BCM than at ENP for each month except January (figure 8). The largest differences in monthly ET rates (greater than 1 inch) occurred from March through July, when water levels were below land surface at one or both sites. Annually, the total ET was 55.7 inches at BCM and 43.5 inches at ENP.

The seasonal pattern of ET and available energy (figure 9) are very similar. However, the differences in monthly ET between the two sites are much more pronounced than the differences in monthly available energy. The mean annual A for 2000 was 138 watts/m^2 at BCM and was 132 watts/m^2 at ENP. The monthly and annual differences between sites in A are small relative to differences in ET, indicating that the sites differ in the amount of A that is utilized for ET.

The difference between the two sites with respect to efficiencies of converting A to ET is seasonal and can be best explained by comparing the EF, or evaporative fraction of available energy ($\lambda E/A$), for the two sites. The effects of differences in A are taken into account by using EF for comparing ET characteristics at the two sites. EF has a distinct seasonal pattern (figure 10); however, the pattern is not the same at both sites. At the BCM, EF is relatively constant during January through October of 2000, and is higher than at the ENP, especially for March through July. Both sites show a decline in EF beginning late in October or early November. At the BCM, the lowest EF for the year occurred in December. At the ENP, low EF also occurred in December, but values of EF as low as in December occurred in April, May, and July as well.

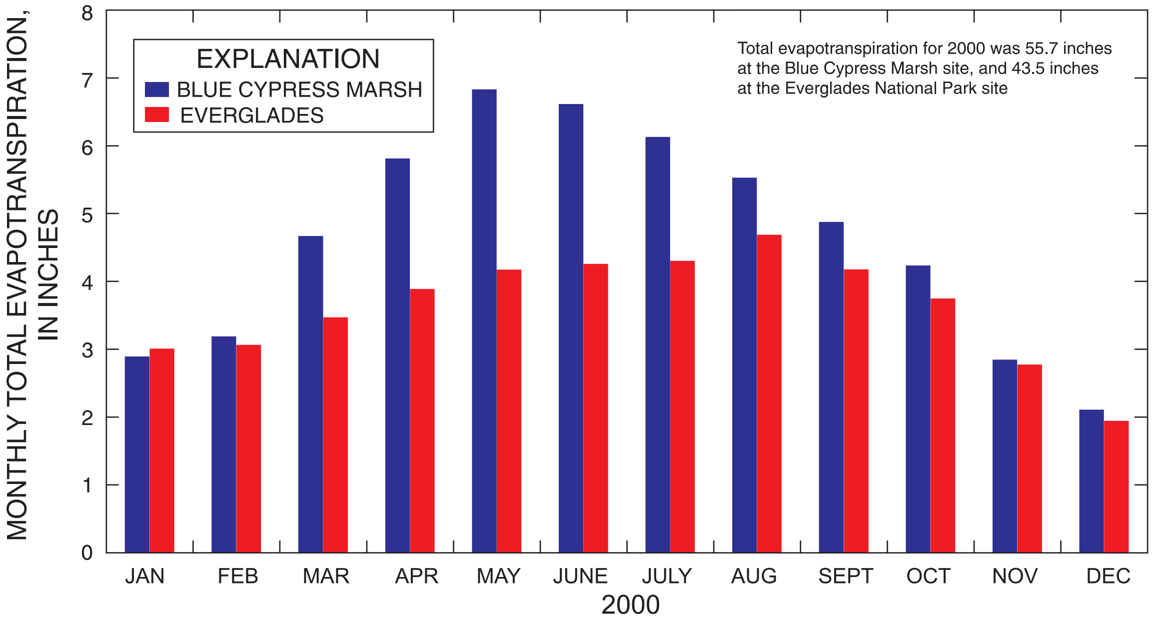


Figure 8. Monthly total evapotranspiration, January 2000 through December 2000.

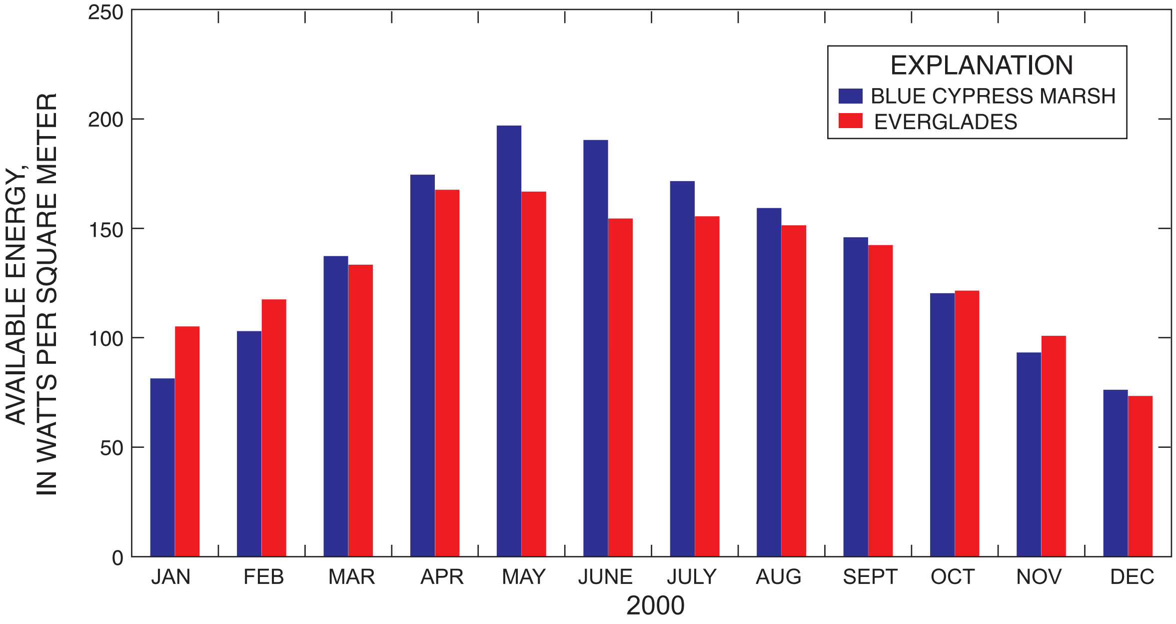


Figure 9. Monthly available energy, January 2000 through December 2000.

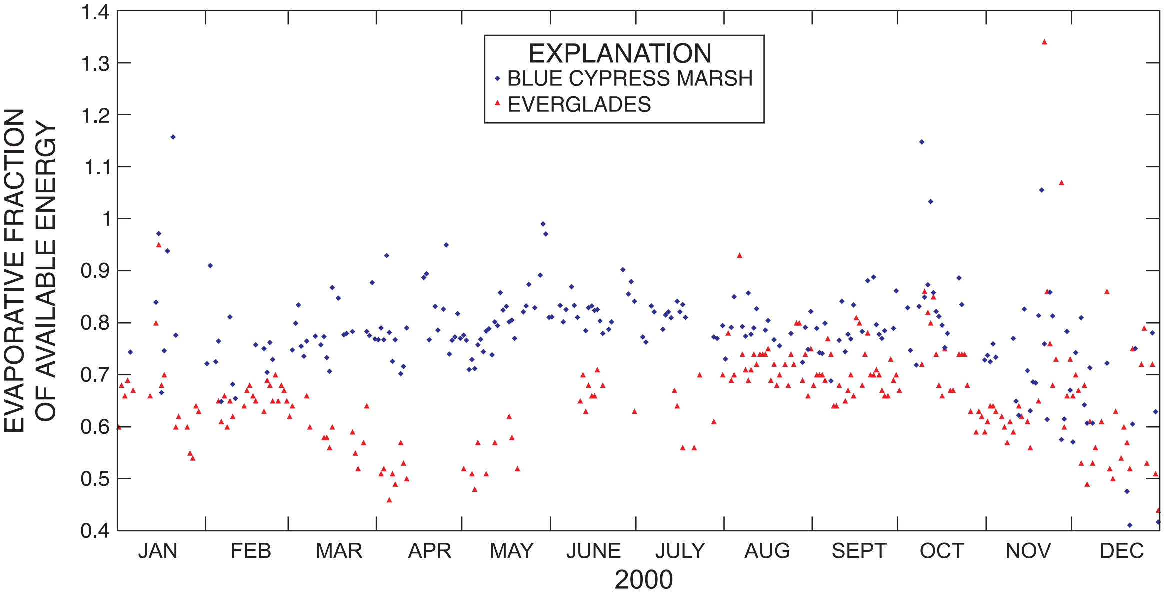


Figure 10. Evaporative fraction of available energy, January 2000 through December 2000 (evaporative fraction is the ratio of latent heat to available energy).

The seasonal pattern of EF at the ENP probably is related to proximity of water levels to the land surface. German (2000) proved that regional models of ET in the ENP could be constructed using a modified Priestley-Taylor ET model in which the model coefficient α is expressed as a function of water level and R_s. Declines in water level at the ENP site beginning in March and ending in June appear to correspond to the low EF during that period. Similar declines from October through December also seem to correspond to the low EF, although there is considerable daily variation in EF that probably is related to other factors, such as variation in R_s.

Conversely, none of the seasonal patterns in EF consistently correspond with changing water level at the BCM. Throughout the dry period from late April through June, when the water level was below land surface, there was no evidence of a decline in EF. Not until October 2000 did EF at the BCM show a decline, and this decline in EF corresponds with a decline in water level to below the land surface.

CONCLUSIONS

The annual total ET at BCM was 55.7 inches and at ENP was 43.5 inches which is a relatively large difference in ET rate and is not explainable by differences in annual A (138 watts/m^2 at BCM and 132 watts/m^2 at ENP for 2000). The EF apparently is related to water level at the ENP site but not at the BCM site. The reason for this difference in behavior of EF is not understood, but probably is related to the differences in plant cover and soil type between the two sites. The thick sawgrass cover at BCM apparently is able to transpire at maximum efficiency even when the water level is more than 2.5 feet below land surface. The thick peat soil layer may play a role in this high EF even during low-water conditions by providing a reservoir of soil moisture from which the sawgrass can draw. Additionally, the sawgrass coverage at BCM is relatively uniform and thick, and the incident solar radiation only penetrates the top of the sawgrass; however, in some parts of the ENP, vegetative cover is thinner and less extensive. Heating of the sawgrass probably is less than heating of the land surface in exposed locations, so that the utilization of A for H flux likely is less at the BCM site than at the ENP. Less H transport relative to λE transport would cause a relatively high EF.

Ongoing research at these two sites to determine reasons for these differences in EF includes study of the moisture-retention capacity of the soils, comparison of leaf-area indices determined using spectrophotometric recorders, and determination of mass of transpiring material per unit area.

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