Research Article

Energy Budget on Various Land Use Areas Using Reanalysis Data in Florida

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Energy budget is closely related to the hydrological cycle through evapotranspiration (ET) or latent heat. Hence, quantifying the energy budget on different land uses is critical for understanding the water budget and providing useful land use information for decision makers. However, traditional methods, including in situ measurements and model-only approaches, have deficiencies in data availability, and we have still not yet fully realized how well the energy budgets presented in reanalysis data sets. Therefore, in this study, North American regional reanalysis (NARR) data set from 1992 to 2002 were employed to investigate the energy budget on various land uses (lake, wetland, agriculture, forest, and urban) at a regional scale in Florida. The results showed that the lake and urban areas had high values of energy budget, evaporation, and low Bowen ratio, while the wetland areas have the opposite trends because of the lowest evaporation rate. During drought periods, Bowen ratio, surface temperature, and sensible heat were becoming higher than those of normal years conditions. Finally, by comparing with the observed data, we found NARR had better assimilation of precipitation observations and demonstrated the land use effects from the different coefficient of correlation relationships.

1. Introduction

The surface energy budget closely relates to the hydrological cycle, since evapotranspiration (ET) or latent heat (LE) is a key relationship between energy and water budgets [1]. The partitioning of net radiation markedly depends on the amount of available water on the surface [2–6]. For example, if the soil moisture drops below a critical limit, the available soil water coupled with available energy limit the evaporation rate and finally reduce rainfall and affect the water budget. Therefore, quantifying energy budget above plant canopies is critical for understanding hydrology cycles and provides insights for improving modeling of future regional and global climate regimes [7, 8].

Moreover, at the land-atmosphere boundary layer, land-atmospheric interactions govern the energy balance and reflect the natural coupling between boundary conditions and rainfall processes [9, 10]. These interactions affect the

daily temperature range, process in the atmospheric boundary layer, cloud cover, rainfall, differential heating, and atmospheric circulations. Hence, land use changes could have both immediate and long-lasting impacts on hydrological processes, altering balance between rainfall and evapotranspiration and the resultant runoff [11]. In short-term impacts, disruptive land use changes disrupt the hydrological cycle either increasing the water yield or through diminishing or even eliminating the low flow in some circumstances [12–14]. While, in long-term impacts, the reductions in evapotranspiration and water recycling arising from land use changes may initiate a feedback mechanism that results in reduced rainfall [15].

However, a disproportional majority of existing energy and water balance studies have been conducted in grasslands and forests, and only few studies have been assessed other land uses such as lake and wetland [16]. For example, these conventional techniques like eddy covariance (EC) and

Bowen ratio (BR) have applied to several land uses such as grassland [17–21], forests [22–27], mango orchard [28], garlic [29], grapes [30], pecans [31], citrus [32], peach [33], olives [34], grapes [35], and corn soybean [8]. Besides, these conventional techniques do not provide spatial trends (or distribution) at the regional scale especially in regions with advective climatic conditions. Most of climate data come from the meteorological stations, which are point measurements, and weather stations are scarce in remote areas and not uniformly distributed. Further, characterization of the surface hydrologic cycle requires adequate long-term records of not only precipitation but also runoff and evaporation, but such records are lacking in observational data [1].

The NCEP North American regional reanalysis (NARR), which includes model based four-dimensional data assimilation procedures, is a long-term, consistent, high-resolution climate data set for the North American domain [36]. These data sets may provide great possibility for more accurate evaluation of interactions of the land surface and atmosphere. In previous research, we had studied water budgets on various land use areas by using NARR data set, and the results showed that NARR could provide reasonable hydroclimatic variability (e.g., precipitation recycling) and assess the associated impacts of land use/cover change [6]. Therefore, in this study, we try to (1) investigate energy balance on various land uses (lake, wetland, agriculture, forest, and urban) at regional scale, (2) understand how drought events, seasonal, and interannual variations in climatic variables affect the energy and water exchange between atmosphere and land use, and (3) determine how well the energy and water cycles are presented in NARR data sets.

2. Data Set

The NARR data, the NCEP regional eta model and its data assimilation system, and a version of the “Noah” land surface mode are the long-term, dynamically consistent, high resolution, high frequency meteorology and hydrology data set for the North American domain [36]. In addition, it adopts many observed quantities in its data assimilation scheme, including gridded analyses of rain gauges precipitation over the continental United States (CONUS), Mexico, and Canada [37]. The data sets and observed variables used in North American regional reanalysis included rawinsondes (temperature, wind, and moisture), dropsondes (temperature, wind, and moisture), pibals (wind), aircrafts (temperature and wind), surface (pressure), and geostationary satellites (cloud drift wind) [36]. Hence, this regional reanalysis is produced at high spatial and temporal resolutions (32 km, 45-layer, 3-hour) and spans a period of 25 years from October 1978 to December 2003. Full details of the NARR products can be found online at <http://www.emc.ncep.noaa.gov/mmb/rrean/>.

The strengths of NARR include its assimilation of precipitation observations and its high spatial-temporal resolution. Precipitation assimilation constrains the diurnal cycle of precipitation, which is poorly captured by current convection schemes. Moreover, assimilation of near-surface humidity constrains latent and sensible heat flux partitioning, which

is often poorly captured by land surface models [3, 4, 6]. Therefore, it is expected that this dataset will be useful not only for energy and water budget studies but also for analysis of atmosphere land relationships. However, we still need to verify how well the energy budgets are presented in NARR data set in this study. NARR variables in this study are basically a function of the model parameterizations, including latent heat, sensible heat, and surface temperature. The study here applies the 11-year period of NARR analyses from 1992 through 2002, utilizing monthly averages of the data.

3. Study Area

The climate in Florida is subtropical, humid with a rainy, wet season extending from May through October. Most areas in Florida receive at least 1270 millimeters of rain annually. The long-term annual mean temperature is 22.4 (± 0.6)°C based on historical records of a weather station located in Kissimmee, Florida (Southeast Regional Climate Center, <http://www.sercc.com/>). This state, however, has large variations in total annual precipitation. Floods that occur one year may be followed by drought the next year [38].

3.1. ENSO in Florida. In Florida, El Niño-Southern Oscillation (ENSO) often influences temperature, precipitation, and upper-level wind, which in turn results in flood, drought, and wildfires [39]. These impacts are stronger during winter and spring months than the summer months. A strong El Niño phenomenon occurred in fall and winter of 1997–1998 when rainfall was above normal for most of the state and temperature was cooler. Nevertheless, by late 1998, a strong La Niña event was in effect, which continued through 2001 [40]. The La Niña brings higher temperature and dry weather in Florida. Lower than normal precipitation caused a severe statewide drought in Florida during period of time. According to Wildfire statistics, it showed 25,137 fires burned 1.5 million acres between 1998 and 2002 [41]. Finally, rainfall that occurred in late 2002, in 2003, and from a tropical storm and four hurricanes in 2004 ended this drought.

3.2. The Selected Areas. In this study, data from 1992 national land cover dataset on five different land uses in six 32 × 32 km regional study areas were selected as shown in Figure 1. These land uses include urban, forest, and agriculture in Northeast Florida, lake, wetland, and agriculture in South Florida based on Florida’s different climatic zones (Figure 2). In the northeast of Florida, the climate is somewhat cooler and receives abundant precipitation between 1000 and 1500 mm annually, thus enabling the production of specialized crops. Therefore, a regional agriculture land use, located in west Alachua and devoted to forage, hay production and silage corn, was selected for studying the energy budget. Moreover, the Ocala National Forest area was selected as a regional forest land use area because extensive pine plantations are relatively common in North Florida [42]. Finally, we chose the urban area, Jacksonville, for the study area because substantial population growth has occurred, causing an expansion of

FIGURE 1: Six selected $32 \times 32 \text{ km}^2$ regional study areas along with land use/land cover from the 1992 national land cover dataset. The red gridline is a $32 \times 32 \text{ km}^2$ resolution grid from North American regional reanalysis dataset (revised from [6]).

urban and developed land. Within 30 years, the population is increased by more than 140 percent, suggesting larger urban areas as in Orlando, St. Petersburg, Tampa, and Jacksonville.

While, in the South Florida, the climate is generally frost-free and subtropical and annual rainfall is about 1400 mm. The main regional characteristics are wetland, lake, agriculture, and urban areas (Figure 1). The Everglades region is

a subtropical wetland that covered much of South Florida and comprises over 4000 square miles stretching from Lake Okeechobee in the north to the Florida Bay at the southern end of the peninsula. Hence, it was selected to represent the regional $32 \times 32 \text{ km}$ grid of wetlands in South Florida. Lake Okeechobee (Figure 1), the second largest freshwater lake in the U.S covering a surface area of 1800 square km,

FIGURE 2: Map of Florida depicting the four regions of the state [40].

with an average depth of 2.7 m, is a large, shallow, eutrophic lake located in South Central Florida and is frequently hit by hurricanes. As the central part of a larger interconnected aquatic ecosystem and as the major surface water body, Lake Okeechobee provides a number of societal and environmental service functions including water supply for agriculture and urban areas [43]. Therefore, investigating impacts of drought events on the lake is very critical and necessary. Finally, the Everglades Agriculture Area (EAA), a small portion of the Everglades Region consisting of artificially rich organic soil supporting a thriving agriculture industry with annual benefits around \$500 million, was also considered for the study [44]. Comparing national land cover dataset of two different periods of 10 years interval, Figures 1 and 3, the land use changes could be monitored and detected. The regional agriculture land use, which is located in West Alachua, changed the land use from row crop in 1992 to pasture hay in 2001, but other land use areas did not change appreciably within the 10-year period. Hence, in this study, we assumed land use types of the selected areas did not have huge differences from 1992 to 2002 (Figures 1 and 3).

4. Methodology

4.1. Energy Budget. Monthly data from 1992 through 2002 NARR data set that includes latent heat, sensible heat, and surface temperature were utilized to evaluate energy budgets on various land uses using the energy balance equation expressed as

$$R_n = H + LE + G, \quad (1)$$

where R_n is net radiation flux at interface between land cover and atmosphere; G is conductive soil heat flux; H represents sensible heat (heat exchange by convection); and LE is latent heat (water vapor condensation or water evaporation from surfaces and plant transpiration). The conductive soil heat

flux would be neglected in this equation because it is relatively small [45]. The ratio of H and LE is used to calculate the Bowen ratio, B .

4.2. Monthly Anomaly Pattern. To determine anomaly trends during the study period, the monthly averages of the climatology parameters, which include actual evaporation, latent heat, sensible heat, and surface temperature, were calculated. Individual monthly anomaly was then calculated as percent departure from the 11 years average of monthly averages using

$$P_a = \left(\frac{P_o - P_m}{P_m} \right) \times 100, \quad (2)$$

where P_a is the respective monthly percent anomalies, P_o is monthly climatology parameters, and P_m is the long-term average of climatology parameters.

5. Results and Discussions

In this study, seasonal, interannual variations and land use effects would be considered in analyzing the 11-year NARR data set. Figure 4 showed the average latent heat in Northeast Florida. In Northeast Florida, for the different land use types, the trade of average latent heat is decreased from 1992 to 2002. The highest annual latent heat was on the agriculture area in 1996 of 96.33 W/m^2 , while the lowest value was in 2000 of 73.67 W/m^2 on the agriculture area.

Figure 5 presented the average annual latent heat in South Florida. The average annual latent fluctuated from 1992 to 1999 and reached the highest values in 1998 on the agriculture, wetland areas and in 1999 on the lake area. Next, the values are declined and reached the lowest values in 2001 on the three study areas. Finally, the trend went up in 2003. In Table 1, the maximum and minimum values of latent heat on the selected land use areas in both regions are presented with the years of occurrence. From Table 1, we find that the selected areas had the lowest latent heat during the drought years.

The seasonal variations of the average monthly latent heat in Northeast Florida were shown in Figure 6, while those of South Florida were presented in Figure 7. In Northeast Florida, higher average values of monthly latent heat were observed between April and September, on the urban and forest areas, while on the agriculture area, the higher values occur in July and lower values were observed in December and January. These variations were listed in Table 2 for the selected land use areas. In South Florida, the wetland area, located in the Everglades, had the highest values of average monthly actual evaporation and latent heat in June, with values of 3.43 mm/day and 99.09 W/m^2 , respectively. It has been suggested that much of the rainfall in South Florida is based on the evaporation in the Everglades [46]. The authors also suggested that the effect of water vapor movement from the ocean to the north due to wind action induces evaporation on the Lake Okeechobee area and the surrounding agriculture area (Figures 1 and 3), leading to higher values of actual evaporation in July and August. Lower values were observed in winter (see Table 2).

FIGURE 3: Six selected $32 \times 32 \text{ km}^2$ regional study areas along with land use/land cover from the 2001 national land cover dataset. The red gridline is a $32 \times 32 \text{ km}^2$ resolution grid from North American regional reanalysis dataset (revised from [6]).

5.1. Monthly Actual Evaporation and Latent Heat Anomaly. Figure 8 showed the time series of monthly latent heat anomaly trends for the Northeast Florida. These anomalies were positive from March to September on the three land uses, with the values between 0.84% and 50.09%. However, during the drought years, March 2000 through 2001, these

anomalies dropped to negative values in all study areas as shown in Figure 8.

Figure 9 suggest that the positive anomalies in the latent heat values range from 0.79% to 47.23% for March and October. However, in May, the lake area had negative values in latent heat, and negative values were also observed during

TABLE 1: Annual variation of actual evaporation and latent heat flux in the selected land use areas.

Land use	Actual evaporation (mm/d)		Latent heat flux (W/m^2)		Year reported	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Northeast Florida Region						
Urban	3.20	2.88	96.27	83.17	1992	2001
Forest	3.11	2.66	90.00	77.00	1995	2000
Agriculture	3.23	2.54	93.33	73.67	1995	2000
South Florida Region						
Lake	3.53	3.08	102.42	89.08	1999	2001
Wetland	2.69	2.33	77.50	67.58	1993	2001
Agriculture	3.34	2.48	96.75	72.25	1995	2001

TABLE 2: Seasonal variation of monthly actual evaporation and latent heat flux in the selected land use areas.

Land use	Actual evaporation (mm/d)		Latent heat flux (W/m^2)		Months reported	
	Max	Min	Max	Min	Max	Min
Northeast Florida Region						
Urban	3.93	1.90	113.63	55.72	July	January
Forest	4.00	1.52	115.36	43.72	July	December
Agriculture	4.35	1.49	126.00	43.18	July	December
South Florida Region						
Lake	3.83	2.93	110.90	84.72	August	February
Wetland	3.43	1.52	99.09	44.09	June	December
Agriculture	4.21	1.76	110.90	50.81	July	January

FIGURE 4: Average annual actual latent heat in Northeast Florida.

FIGURE 6: Average monthly latent heat in Northeast Florida.

FIGURE 5: Average annual latent heat in South Florida.

FIGURE 7: Average monthly latent heat in South Florida.

FIGURE 8: Time series monthly latent heat anomaly trends for Northeast Florida.

FIGURE 9: Time series monthly latent heat anomaly patterns for South Florida.

the drought years for all research areas, except in April of both drought years for the wetland and agriculture areas.

5.2. Monthly Sensible and Heat Variations. Based on the energy budget (1), the available land surface energy was partitioned into latent heat and sensible heat, and as more energy partitioned into latent heat, less energy converted to sensible heat. Figures 10(a) and 10(b) showed the average annual and monthly sensible heat in Northeast Florida for all land use areas. During drought years, most of land surface energy would be partitioned into sensible heat. Hence higher sensible heat was observed on the urban, forest, and agriculture area with values of 44.08 W/m^2 , 51.5 W/m^2 , and 51.8 W/m^2 , respectively. Also, during the summer and fall seasons, most of surface energy would convert to latent heat for evaporation thus resulting in lower values of sensible heat from June to December in Northeast Florida. Hence, on all three land uses, lower average monthly sensible heat values were observed as 23 W/m^2 and 57.63 W/m^2 in summer and fall, respectively, while the higher values were observed in winter and spring, as 25.09 W/m^2 and 84.09 W/m^2 , respectively.

In the south, the average annual and monthly values of the sensible heat also varied with land uses as shown in Figures 11(a) and 11(b). These annual values range from 41 W/m^2 in 2000, 55.41 W/m^2 in 2000, and 51.58 W/m^2 in

2001 on the lake, wetland, and agriculture areas, respectively. During summer and fall seasons, when most of the land surface energy converted to latent heat for evaporation, lower sensible heat values were observed on the three land uses, with values between 15.18 W/m^2 and 45.54 W/m^2 . The higher values of the average monthly sensible heat were in April on the wetland and agriculture areas, with values of 77 W/m^2 and 67.54 W/m^2 , respectively, and in May on the lake, with the values of 44.54 W/m^2 .

5.3. Monthly Sensible Latent Heat Anomaly. Interannual variations in monthly sensible heat in Northeast Florida were shown in Figure 12(a). In normal years, monthly sensible heat anomalies were negative from June to January, with values between -0.71% and -54.88% , while the positive values were from February to May, with values between 0.88% and 58.32% for all three land use areas. However, during the drought years, the positive sensible heat anomalies were shown in June 1998, from June to August in 1999 and 2000, with values between 0.84% and 263.57% on all three land uses. It has been suggested that soil moisture acts as a strong control on the partitioning between sensible heat flux and latent heat flux at the surface (the Bowen ratio) modulating precipitation over a given basin [47, 48]. Hence, different land use types have different responses to the drought events. For example, the agriculture area, which has shallow roots containing lower soil moistures, had highest sensible heat anomalies in June 1998, May of 1999 through 2002, and April 2000, with values between 183.95% and 308.68% , while other land use areas such as the urban and forest areas just had higher anomalies during the drought period.

It has also been suggested that surface temperature is a factor in sensible heat variation and transfer. When the surface is warmer than the air above, heat will be transferred upward into the air as positive sensible heat to warm up air temperature. Figure 12(b) presented interannual variations in monthly surface temperatures in Northeast Florida. In normal years, the monthly surface temperature anomalies were negative from November to April, with values between -0.67% and -46.34% , while the positive values were from May to October, with values between 2.84% and 36.82% . During the drought years, however, higher surface temperatures transferred higher sensible heat, which resulted in a higher surface temperature anomaly in June 1998, with a value of 53.95% , and a higher sensible heat over the agriculture area, with a value of 269.57% .

Figure 13(a) showed the interannual variations in monthly sensible heat in South Florida. In normal years, negative monthly sensible heat anomalies were observed from June to December, with the values between -2.67% and -68.4% , while the positive anomalies were observed from February to May, with values between 0.68% and 68.52% on the three land uses. During drought years, the sensible heat anomalies were from February to May, especially on the lake and agriculture areas, with the values between 30.89% and 188.63% , respectively.

Figure 13(b) presented the interannual variations in monthly surface temperature in South Florida. In normal

FIGURE 10: (a) Average annual sensible heat in Northeast Florida. (b) Average monthly sensible heat in Northeast Florida.

FIGURE 11: (a) Average annual sensible heat in South Florida. (b) Average monthly sensible heat in South Florida.

years, high values occurred between April and May with values between 1.05% and 23.07%. During the drought years, the lake and agriculture areas had higher surface temperature anomalies with higher values in April to May of 1999 through 2002, with values between 6.54% and 29.57%.

5.4. Monthly Bowen Ratio. During drought, the Bowen ratio is higher suggesting that partitioning of net radiation is skewed, with more heat going into the sensible heat flux and less into the latent flux. The increased sensible heat flux acts to heat the canopy and boundary layer. Figures 14(a) and 14(b) show the average annual Bowen ratio in Northeast and South Florida, respectively. Hence, during the drought years, higher Bowen ratios were shown on the agriculture areas with values of 1.19 in 2000 in Northeast Florida and 1.5 in 2001 in South Florida. This shift indicates that increased sensible heat was gained compared to latent heat as water flux from the ecosystem abruptly decreased.

Figures 15(a) and 15(b) show the average monthly Bowen ratio in Northeast and South Florida, respectively. The seasonal variation was clearly concave-sharped and the lower values occurred from June to September, with a range of 0.24 and 0.69 in Northeast Florida and 0.14 and 0.48 in South Florida. Higher values were observed in early spring, with

values between 0.47 and 1.79 in Northeast Florida and 0.45 and 1.32 in South Florida.

5.5. Monthly Bowen Ratio Anomaly. Figures 16(a) and 16(b) show the interannual variations in monthly Bowen ratio in Northeast and South Florida, respectively. In Northeast Florida, during the drought year, the values of Bowen ratio were high on the three land use areas with the agriculture area as the highest in May. This suggests that a decrease in evapotranspiration through the growing season due to the decrease of soil moisture and maintenance of the energy balance through changes in the sensible heat and latent heat fluxes. While in South Florida the highest sensible heat flux occurred in February of 2001 when the surface temperature was above normal by 11.96%, hence showing negative anomalies. It was also noted that under drier conditions, the availability of soil moisture becomes the primary source of moisture for ET, which strongly controls Bowen ratio and therefore affects the surface temperature and evaporation rate.

5.6. Energy Budget Balance. Tables 3 and 4 presented the 11-year mean energy budget terms for the selected land use areas in Northeast and South Florida, respectively. In this study,

FIGURE 12: (a) Time series monthly sensible heat anomaly patterns for Northeast Florida. (b) Time series monthly surface temperature anomaly patterns for Northeast Florida.

FIGURE 13: (a) Time series monthly sensible heat anomaly patterns for South Florida. (b) Time series monthly surface temperature anomaly patterns for South Florida.

the total net radiation is defined as the summation of latent and sensible heat, and the evaporation rate is defined as the ratio of latent heat/net radiation. In Northeast Florida, the urban area located at St. Johns River had the highest net radiation, latent heat, evaporation rate, actual evaporation, and lower sensible heat, while the agriculture area had lower net radiation and latent heat. In South Florida, the lake area had the highest net radiation, latent heat, evaporation rate, and lower sensible heat and Bowen ratio. However, because wetlands have hydric soil, which keeps water on the surface, the net radiation, latent heat, evaporation rate, and actual evaporation were lower, while the sensible heat and Bowen ratio were higher. In general, the agriculture area had a similar Bowen ratio, with a value of 0.55 in both study areas. The open area was observed to have the lowest Bowen ratio, and the wetland had the highest. In the report by [49], they provided in situ mean monthly weather parameters data (from 1994 to 2003) from a weather station at a constructed wetland (at Stormwater Treatment Area 1 West), including actual evaporation and rainfall data. Hence, we compared actual evaporation from NARR and in situ data, and results showed that the NARR data set would significantly underestimate

evaporation on May while overestimate on the lake area from October to January (see Figure 17(a)). We also calculated coefficient of correlation between the NARR and observations data. The results indicated that the wetland area had the highest coefficient of correlation, 0.92, while the lake area had the lowest one, 0.37. Finally, Figure 17(b) demonstrated that the NARR has good relationships with the observations in mean monthly rainfall data, and the coefficients of correlation were 0.94 on the three study areas. Hence, in conclusion, NARR had better assimilation of precipitation observations and could reflect land use effects that are in the actual evaporation estimation; the wetland areas demonstrated the highest coefficient of correlation with the same land use type observations data.

6. Summary and Conclusions

In this study, NARR data set from 1992 to 2002 were employed to investigate the energy budget on various land uses (lake, wetland, agriculture, forest, and urban) at regional scale in Florida. In Northeast Florida, the urban area had higher

FIGURE 14: (a) Average annual Bowen ratio in Northeast Florida. (b) Average annual Bowen ratio in South Florida.

FIGURE 15: (a) Average monthly Bowen ratio in Northeast Florida. (b) Average monthly Bowen ratio in South Florida.

TABLE 3: Annual mean (1992–2001) energy budget for various land uses in Northeast Florida.

Energy budget	Urban	Forest	Agriculture
Net radiation (W/m^2)	126.424	126.015	122.962
Latent heat (W/m^2)	89.159	85.462	85.280
Sensible heat (W/m^2)	37.265	40.553	37.682
Evaporation rate	0.703	0.672	0.695
Actual evaporation (mm/day)	3.085	2.956	2.948
Bowen ratio	0.430	0.507	0.546

TABLE 4: Annual mean (1992–2001) energy budget for various land uses in South Florida.

Energy budget	Lake	Wet land	Agriculture
Net radiation (W/m^2)	127.11	121.80	126.27
Latent heat (W/m^2)	97.31	73.48	88.30
Sensible heat (W/m^2)	29.80	48.32	37.98
Evaporation rate	0.77	0.60	0.70
Actual evaporation (mm/day)	3.37	2.54	3.05
Bowen ratio	0.33	0.70	0.55

net radiation, latent heat, evaporation rate, lower sensible heat and Bowen ratio, while the agriculture area had lower

net radiation, latent heat, actual evaporation, and higher Bowen ratio. In South Florida, Lake Okeechobee (lake) had higher net radiation, latent heat, evaporation rate, actual evaporation, lower sensible heat, and Bowen ratio, while the wetland area had lower net radiation, latent heat, evaporation rate, higher sensible heat, and Bowen rate because of lower evaporation. From the annual energy budgets, the agriculture in both study areas had similar Bowen ratio therefore suggesting that Bowen ratio may be used for identifying the characteristics of different land uses.

Under wet conditions, ET is principally limited by the atmospheric demand of water vapor, driven by advection and radiation. This suggests why the lake areas have higher actual evaporation, latent heat, evaporation rate, and lower Bowen ratio with higher net radiation. However, during the drought year, most of the surface energy would be partitioned into sensible heat and, hence, lower average annual evaporation and latent heat as shown by various land uses with higher average monthly sensible heat in summer and fall seasons. Moreover, during drier conditions, the availability of soil moisture becomes the primary control of ET, and the differences in plants response to access water often dictated by the rooting depth can result in contrasting evaporative losses across vegetation types [50]. Therefore, in Northeast Florida, negative evaporation and latent heat were observed

FIGURE 16: (a) Time series monthly Bowen ratio anomaly patterns for Northeast Florida. (b) Time series monthly Bowen ratio anomaly patterns for South Florida.

FIGURE 17: (a) Comparison of average monthly evaporation from the NARR South Florida study areas with the observations at Stormwater Treatment Area 1 West constructed wetland. (b) Comparison of average monthly rainfall from the NARR South Florida study areas with the observations at Stormwater Treatment Area 1 West constructed wetland.

in June 1998, April 2000, and May of 1999 through 2002 for agriculture area, but the forest and urban areas had positive values in these months. In South Florida, the agriculture area had lower evaporation and latent heat within the drought period than the values for the lake and wetland areas. Finally, by comparing them with the observed data, we found out North American regional reanalysis data (NARR) could be used to study the pattern of major hydroclimatic variability (e.g., precipitation recycling) and assess the impacts of land use land cover change impacts.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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