Research Article

Water Budget on Various Land Use Areas Using NARR Reanalysis Data in Florida

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1992 to 2002 data from North American Regional Reanalysis (NARR) were used to investigate water budget on five land use areas: urban, forest, agriculture, lake, and wetland in the state of Florida, USA. The data were evaluated based on the anomalies of rainfall, evaporation, and soil moisture from the average condition. The anomalies were used to investigate the effect of extreme conditions on water budget parameters for various land uses in both northeast and south of Florida. The results showed that extreme events such as La Niña strongly affected the water budget on land-use areas in both regions as the negative monthly rainfall anomalies were observed during the 1999-2000 event, while El Niño and thunderstorms in summer caused positive rainfall anomalies with more than 70% in all study areas. Higher rainfall led to higher soil moisture anomalies for the agriculture, forest, and wetland from 1992 to May 1998 in both study regions. However, soil moisture becomes primary source for evaporation in drier conditions, and differences in capacity of plants access water, often dictated by the rooting depth, can result in contrasting evaporative losses across vegetation types. Hence, the forest, which had the deeper roots, had lower soil moisture anomalies, but higher evaporation anomalies than agriculture area during the drought event.

1. Introduction

The catchment water cycle, assuming steady state, consists of precipitation (P), discharge (Q), and evapotranspiration (ET) [1]. More specifically, estimations of water cycle components include (1) atmosphere budget, which consists of sources (surface evaporation and evapotranspiration) and sinks (rainfall and cloud) as well as the transports between them, and (2) terrestrial water budget, which includes the soil moisture storage, surface/subsurface runoff, precipitation, and evapotranspiration [2].

Terrestrial and atmospheric water cycles are intrinsically coupled and linked through evapotranspiration and precipitation [3–5]. Precipitation and snowmelt influence plant available moisture during the growing season, which impacts water and energy cycles through vegetation canopy controls on transpiration, plant atmosphere exchanges of water vapor, and the partitioning of net radiation energy into sensible and latent heat fluxes [6].

Humans are an active and increasingly significant component of the hydrologic cycle [7]. For example, land clear-

ance for waste disposal and other activities, such as agriculture, urbanization, and the conversion of native grasslands causes significant hydrological disruptions that adversely impact the water resources of the locality and beyond. Moreover, Human activities are significantly changing the global environment and climate, in a variety of diverse ways beyond the effects of human emissions of greenhouse gases. Within the context of global climate change, land use change and climate change are interrelated, and there is a mounting need for predicting watersheds response to these changes [7]. Therefore, better understanding of the terrestrial water budget would improve our knowledge of the current climate, global hydrological cycle, and its dynamics and thus improve our skills in modeling, forecasting, and analyzing the land-atmosphere system.

The widely used approaches to evaluate the terrestrial water cycle can be divided into three categories: (1) observations based on in situ measurements: direct observation is the most traditional approach for water budget estimates and considered reliable at the scale of measurement. However,

several basic atmospheric hydrological variables, such as evaporation, precipitation, and runoff, are poorly or/and sparsely measured [2]. At regional to continental scales, dense networks of instruments are too expensive and long-term observation data are always limited. (2) Derived estimates based on spatially-remote-sensed observations: remote sensing and the corresponding retrieval techniques have come of age as a viable source of data collection, particularly in parts of the world where in situ data networks are sparse. Many hydrological state variables and fluxes can be estimated through satellite remote sensing but still are inadequate [8]. (3) Estimates based on land surface models: observations can fail to provide relevant required information with sufficient space and time resolution. High-resolution climate or land use model could be a constitutive tool to generate hydrological cycle components that are difficult to measure. An advantage of these model-derived data is their self-consistency and that they can be used by many to model the land surface water and energy balances. However, a drawback of a model-only approach for water budget estimation is that models are not perfectly parameterized and calibrated as errors and biases exist and propagate through time [2].

Moreover, hydrological processes strongly rely on surface processes, topography, and mesoscale atmospheric circulations. Investigating water budget on various land uses is necessary and critical. However, in previous studies, models have related land use effects and changes in regional water cycles [9–15], but a disproportional majority of water budget studies have been in grasslands and forests, and only few studies have been assessed in agricultural, wetland, and lake areas [16].

To improve these situations, in this study, North American Regional Reanalysis (NARR) data, which include model-based four-dimensional data assimilation procedures, were used for investigating water budget on various land uses. Data assimilation techniques, the integration of the virtues of observations and modeling by fusing them together, have been studied and used for decades in meteorological and oceanic applications [2]. The NARR data sets may provide a great possibility for more accurate evaluation of interactions of the land surface-atmosphere. Therefore, the first objective of this study is investigating the water balance on various land uses (lake, wetland, agriculture, forest, and urban) at regional scale. Moreover, El Niño-Southern Oscillation (ENSO), which is one of the most studied patterns of the world climate, includes a strong natural interannual climate signal that affects the surface climate in numerous regions. The effect of ENSO on the US surface temperature has been documented in previous studies [17–23]. However, few studies have investigated the role of ENSO on the individual terms of the surface water balance and descriptions of changes in hydrologic cycle over different land uses. Hence, the second objective of this study is using the NARR data to understand how drought events, El Niño, La Niña and seasonal, interannual variations in climatic variables affect the energy and water exchange between atmosphere and land use.

2. Data Set

This study employs the NARR dataset developed at the Environmental Modeling Center (EMC) of the National Centers for Environmental Prediction (NCEP). This dataset is based on the April 2003 frozen version of the operational Eta Model and its associated Eta Data Assimilation System (EDAS) and uses many observed quantities in its data assimilation scheme, including gridded analyses of rain gauges precipitation over the continental United States (CONUS), Mexico, and Canada [24]. Hence, this regional reanalysis is produced at high spatial and temporal resolutions (32 km, 45 layer, 3 hours) and spans a period of 25 years from October 1978 to December 2003. Full details on the NARR products can be found online at <http://www.emc.ncep.noaa.gov/mmb/rrean/>.

The EDAS is successful with downstream effects, including two-way interaction between precipitation and the improved land-surface model [25]. Reference [26] demonstrated significant regional improvements in a number of variables when using precipitation assimilation over the CONUS. 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, NARR still carries important, but unavoidable, model dependence. Hence, we still need to verify how well the water cycles are presented in NARR dataset in this study.

NARR variables in this study are basically a function of the model parameterizations; these include soil moisture, runoff, actual surface evaporation, and precipitation. The study applied a 11-year period of NARR dataset from 1992 through 2002, while utilizing monthly averages of the data.

3. Study Area

This study examined the water balance on various land use sites in Florida. The climate in Florida is humid subtropical with a rainy wet season extending from May through October. Most areas in Florida receive at least 1270 mm of rainfall annually. The long-term annual mean temperature is 22.4°C based on historical records of a weather station located in Kissimmee, Florida (Southeast Regional Climate Center, <http://www.sercc.com/climate/>). Florida has varied annual precipitation as floods in one year may be followed by drought the next [27].

In Florida, El Niño-Southern Oscillation (ENSO) often influences temperature, precipitation, and upper-level wind, which in turn result in drought and wildfires [28]. These impacts are stronger during winter and spring months than during the summer months. Hence, 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. By late 1998, a strong La Niña event was in effect, which continued through 2001 [29]. During 1998–2002, Florida experienced multiple high-pressure systems with higher temperatures and dry weather that brought a La Niña effect during part of the period. Hence, lower than normal precipitation caused a severe statewide drought in Florida during that period. The drought

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.

was one of the worst ever to affect the state based on precipitation and stream flow data. Wildfire statistics show that 25,137 fires burned 1.5 million acres between 1998 and 2002 [30]. Finally, rainfall that occurred in late 2002, 2003, and from a tropical storm and four hurricanes in 2004 ended this drought period.

In this study, five different land uses in six areas were selected based on Florida different climatic zones and land use/land cover data. Figure 1 presents the 6 selected $32 \times 32 \text{ km}$ regional study areas along with land-use/land cover data from the 1992 National Land Cover Dataset. Three different land uses, urban, forest, and agriculture, are located in Northeast Florida, while the other three are lake, wetland, and agriculture located in South Florida. Figure 2 shows

the map of Florida depicting the four regions of the state. The climate of Northeast Florida is somewhat cooler and receives abundant precipitation between 1000 and 1500 mm annually. The combination of long frost-free periods of more than 240 days and plentiful water has historically enabled the production of specialized crops [31]. For example, the citrus industry focused its intensive orange grove production on the southern interior and southeastern coast of Northeast Florida. Pastureland in Northeast Florida has also been an important agriculture resource. Hence, a regional agriculture land use, which is located west Alachua (Figure 1) and devoted to forage, hay production, and silage corn, was selected for studying the water budget. Moreover, extensive pine plantations, employed for timber production, are

FIGURE 2: Map of Florida depicting the four regions of the State [29].

a relative common use of forests in North Florida. Almost one- third of Florida forestland is commercial pine harvested and regenerated at a relatively fast pace [32]. Therefore, investigating land use effects on the water balance on the forest area is very important. In this study, Ocala National Forest, which is covered by sand pine scrub forest, presents a regional forest land use. Furthermore, substantial population growth has occurred, causing an expansion of urban and developed land. Within 30 years, the population increased by more than 140 percent, from 4.2 million to 10.3 million people. Larger urban areas are prevalent on the Florida peninsula, including Orlando, St. Petersburg, Tampa and Jacksonville. Hence, Jacksonville, which is the largest city in the state of Florida, was selected for a regional urban land use.

South Florida, exposed to onshore breezes, enjoys comfortable temperatures most of the year. The climate is generally frost-free and subtropical and annual rainfall is about 1400 mm. The main regional characteristics in South Florida are wetland, lake, agriculture, and urban areas (Figure 1). The Everglades region is a subtropical wetland, the only one of its kind in the USA [33]. Historically, it covered much of South Florida, comprising over 4000 square miles stretching from Lake Okeechobee in the north to the Florida Bay at the southern end of the peninsula (The South Florida Everglades Restoration Project). Hence, a regional 32×32 km grid of wetlands in the South Florida was selected for a study area. Lake Okeechobee (Figure 1) is a large, shallow, eutrophic lake located in south central Florida, and frequently hit by hurricanes. The Lake is the second largest freshwater lake in the USA and covers a surface area of 1800 square km, with an average depth of 2.7 m. As the central part of a larger interconnected aquatic ecosystem in South Florida and as the major surface water body of the Central and Southern Florida Flood Control Project, Lake Okeechobee provides a number of societal and environmental service functions including water supply for agriculture, urban areas, and the environment

[34]. Therefore, investigating long-term water budgets of Lake Okeechobee is very critical and necessary. Finally, the Everglades agriculture area (EAA), which presents an agriculture land use type in this study, is a small portion of the Everglades region, consisting of artificially rich organic soil. EAA has built a thriving agriculture industry with annual benefits around \$500 million [35], attributable for the most part to sugarcane and winter vegetables.

Figure 3 showed the 6 selected 32×32 km regional study areas along with land use/land cover data from the 2001 National Land Cover Dataset. Comparing National Land Cover Dataset of two different periods of 10-year interval, 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 a lot within the 10-year period. This land use change may change energy balance, *ET* rate, and rainfall and affects water budget and regional climate. Therefore, in this study, land use change effects also could be observed by examining long-term water budgets on various land uses in Florida.

4. Results and Discussions

In this study, monthly dataset from 1992 through 2002 NARR data, which includes precipitation, actual and potential surface evaporation, soil moisture, and runoff, was utilized for studying water budgets on various land uses by using the water balance equation expressed as

$$P = E + \Delta S + R, \quad (1)$$

where P is the precipitation, E is the evaporation, R is the sum of surface and subsurface runoff and S is the water content from snow accumulation, soil moisture, and canopy water.

4.1. Rainfall Variations. Rainfall varies in annual amounts, seasonal distributions, and locations. Figures 4(a) and 4(b) show the average annual precipitation on various land uses in Northeast and South Florida, respectively. In the Northeast, the average annual rainfall was the lowest in 2000 for all land uses, while urban and forest areas had the highest values in 1994 with the agriculture area in 1997. The highest values of average annual rainfall were about 4.31, 3.70, and 3.74 mm/day, on the forest, urban, and agriculture, respectively, whereas the lowest values were about 2.62 mm/day on the three land uses. In South Florida, the three land uses experienced the highest average annual rainfall in 1994, but the lowest values were in 2000. The highest average values of annual rainfall were 3.66, 4.50, and 4.10 mm/day, while the lowest values were 2.27, 2.97, 2.28 mm/day on lake, wetland, and agriculture, respectively.

Seasonal precipitation patterns in Florida vary between summer convective thunderstorms and winter fronts. Figures 5(a) and 5(b) present the average monthly rainfall in Northeast and South Florida, respectively. In the Northeast Florida, three land uses had the highest average monthly rainfall in June, with values of 5.00, 6.26, and 5.88 mm/day and the lowest values exhibited in May, with values of 1.37,

FIGURE 3: Six selected 32 × 32 km² regional study areas along with land use/land cover from the 2001 National Land Cover Dataset.

FIGURE 4: (a) The average annual rainfall in Northeast Florida. (b) The average annual rainfall in South Florida.

FIGURE 5: (a) The average monthly rainfall in Northeast Florida. (b) The average monthly rainfall in South Florida.

1.78, and 1.53 mm/day on the urban, forest, and agriculture, respectively. In South Florida, three land uses had the highest average monthly precipitation in June, with values of 6.26, 8.37, and 6.96 mm/day and the lowest values were in December, with values of 1.54, 1.38, and 1.40 mm/day on lake, wetland, and agriculture, respectively.

4.1.1. Monthly Rainfall Anomaly. To determine anomaly patterns during the study period, 11-year monthly averages of climatology parameters were developed. Individual monthly anomaly was calculated as percent departure from the 11-year 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 anomaly, P_o is the monthly, parameters such as precipitation, soil moisture, actual evaporation, potential evaporation, and runoff, and P_m is the long-term average of parameters. Figures 6(a) and 6(b) show the time series monthly precipitation anomaly patterns for Northeast and South Florida, respectively. Winter of 1997–1998 represents a strong El Niño phenomenon with rainfall anomalies more than 95% above normal that occurred on the three land uses in October 1997 and February 1998. By late 1998, a strong La Niña event was in effect, which continued through 2001. On the three land uses, precipitation anomalies decreased to negative anomaly values between -30% and -87% from October to May in 1999, 2000, and 2001. However, positive anomalies occurred on the three different land uses in March 2001. Hurricanes and thunderstorms are the main sources of rain in Florida. Their frequency and intensity were usually higher in June and August. For example, rainfall anomalies were more than 80% above normal on the three land use areas in August 1992, because of hurricane Andrew. Thunderstorms also caused rainfall anomalies more than 70% above normal in June 1992, 1994, 2001, and 2002 on the three areas. In South Florida, rainfall anomalies were higher than 8% above normal in December 1997 and 35% above normal in February 1998 on the three land uses

because of El Niño effects. During a drought period, rainfall anomalies decreased to negative anomaly values between -50% and -100% from November to May on the three areas. Moreover, hurricane Andrew and thunderstorms in June caused the rainfall anomalies more than 100% above normal on the three land use areas in 1992, 1995, 1999, and 2002, respectively.

4.2. Evaporation Variations. In the hydrologic budget of Florida, ET is the second most important component after precipitation [36]. It is influenced by seasonal changes in climate and can vary considerably within basins with different types of vegetation or different proportions of water surface. Hence, in this study, seasonal, interannual variations and land use effects would be considered in using 11-year actual evaporation reanalysis data. Figures 7(a) and 7(b) show the average annual actual evaporation from 1992 to 2002 on various land uses in Northeast and South Florida, respectively. In Northeast Florida, the highest average of annual evaporation on the urban area occurred in 1992 with a value of 3.2 mm/day and the lowest value was in 2001 with a value of 2.88 mm/day. On the forest and agriculture areas, the highest average values of annual evaporation were in 1996 of 3.11 mm/day and 3.23 mm/day, while the lowest values were in 2000 of 2.66 mm/day and 2.54 mm/day, respectively. In South Florida, the highest values of average annual evaporation were in 1999 of 3.53 mm/day on the lake area, in 1993 of 2.69 mm/day on the wetland, and in 1995 of 3.34 mm/day on the agriculture. The lowest values were in 2001 of 3.08 mm/day, 2.33 mm/day, and 2.48 mm/day on the lake, wetland, and agriculture areas, respectively.

Seasonal variations of the average monthly evaporation in Northeast and South Florida are shown in Figures 8(a) and 8(b), respectively. In Northeast Florida, the higher average values were seen to occur during April–September on the urban and forest areas, with values between 3.25 mm/day and 4 mm/day. However, on the agriculture area, the lowest average monthly evaporation was in May, with the value of 2.94 mm/day, and the highest in July, with a value of 4.35 mm/day. In South Florida, the wetland area, which

FIGURE 6: (a) The time series monthly rainfall anomaly patterns for Northeast Florida. (b) The time series monthly rainfall anomaly patterns for South Florida.

is located in the Everglades, had the highest values of the average monthly evaporation in June, with the value of 3.43 mm/day. It has been suggested that much of the rainfall in South Florida is based on the evaporation in the Everglades [37]. Reference [37] also suggested that the effect of water vapor movement to the north due to wind action from the ocean induces evaporation in the Lake Okeechobee area and the surrounding agriculture area (Figure 1) with higher values of evaporation in July and August. These values range from 4.21 mm/day to 3.83 mm/day for lake and agriculture, respectively.

4.2.1. Monthly Evaporation Anomaly. Interannual variations in monthly evaporation in Northeast and South Florida are shown in Figures 9(a) and 9(b), respectively. In Northeast Florida, monthly evaporation anomalies were positive from March to September with the values between 0.39% and 57.37% above the normal for all three land uses. However, during the drought years, anomalies were negative on the three land uses in March 2000 and 2001. Different land use types are strongly affected by evaporation and also had

different responses to the drought events. For example, on the agriculture area, the negative anomalies were shown in April 2000, May of 1999 through 2002, and June 1998, but the forest and urban areas had positive values in these months. In South Florida, the positive anomalies were shown on all three land use areas from March to October, but the lake area had the negative values in May. During the drought years, the negative anomalies for the land uses were from December to May of 1999 through 2002, which varies between -7.29% and -86.90% , except for the positive values in April 2000 and 2002 on the wetland and agriculture areas.

4.3. Monthly Soil Moisture Variations. Soil moisture reflects past precipitation and evaporation, infiltration, and runoff. In turn, the soil moisture acts as a strong control on the partitioning between sensible heat flux and latent heat flux at the surface modulating precipitation over a given basin [38]. Figures 10(a) and 10(b) show a range of 0–200 mm monthly soil moisture anomalies for agriculture, forest, and wetland areas in Northeast and South Florida, respectively. The urban and lake areas were not evaluated because the

FIGURE 7: (a) The average annual actual evaporation in Northeast Florida. (b) The average annual actual evaporation in South Florida.

FIGURE 8: (a) Seasonal variations of the average monthly actual evaporation in Northeast Florida. (b) Seasonal variations of the average monthly actual evaporation in South Florida.

monthly soil moisture reanalysis data were not available. In Northeast Florida, in winter 1997-1998, the higher rainfall led to the higher soil moisture, with anomalies between 20% and 41% above the normal on the forest and agriculture areas. Wetter soil moisture caused an enhanced moisture flux into the atmosphere from the surface leading to greater specific humidity and enhancing precipitation over regions. Hence, the positive soil moisture anomalies were shown from 1992 to May 1998, which resulted in the higher rainfall, while negative anomalies occurred during the drought event over the regions. Under drier conditions, the availability of soil moisture becomes the primary source of ET , and differences in capacity of plants access water, often dictated by the rooting depth, can result in contrasting evaporative losses across vegetation types [39]. Trees tend to have deeper roots than herbaceous plants [40, 41] and hence could maintain higher ET than crops or grasslands when the supply declines [42, 43]. Therefore, the forest area had lower soil moisture anomalies but higher evaporation anomalies than the agriculture area in the Northeast during the drought event. In South Florida, the agriculture area had negative soil moisture anomalies during the drought event, from February 2000 to July 2001, with the values between -14.95% and

-35.63% , while the wetland area had higher soil moisture or positive anomalies from July 2000 to October 2000. This can be explained by the fact that a wetland soil is saturated with moisture either permanently or seasonally and can slowly release large volumes of water. Hence, as water resources become more and more scarce, wetland provides drought relief for stock and habitat for a range of threatened plants and animals [44].

4.4. Water Budget Balance. Tables 1 and 2 present the mean water budget on various land uses in Northeast and South Florida, respectively. Runoff and potential evaporation were calculated from the dataset while the local soil moisture (dw/dt) is the rate of soil moisture change in time and equals the residual of the surface water balance (i.e., $dw/dt = P - E - R$). However, runoff was not calculated for urban and lake areas due to the non availability of data. Potential evaporation (PE) or potential evapotranspiration (PET) is defined as the amount of evaporation that would occur if sufficient water sources were available. Hence, the difference between potential evaporation and actual evaporation ($PE - E$) was used as a measure of water and energy availability.

FIGURE 9: (a) Interannual variations in monthly evaporation in Northeast Florida. (b) Interannual variations in monthly evaporation in South Florida.

TABLE 1: Annual mean (1992–2001) water budget for various land uses in Northeast Florida.

Water budget	Urban	Forest	Agriculture
Precipitation, P (mm/day)	3.21	3.45	3.36
Evaporation, E (mm/day)	3.09	2.96	2.95
Runoff, R (mm/day)	N/A	0.01	0.01
$*dW/dt$	N/A	0.48	0.39
E/P	0.96	0.86	0.88
Potential evaporation, PE (mm/day)	5.44	5.67	5.39
P/PE	0.59	0.61	0.62
$PE - E$	2.36	2.71	2.44

$*dW/dt$: soil moisture change with time ($W = 0$ –200 mm soil moisture).

TABLE 2: Annual mean (1992–2001) water budget for various land use areas in South Florida.

Water budget	Lake	Wetland	Agriculture
Precipitation, P (mm/day)	3.14	3.78	3.33
Evaporation, E (mm/day)	3.37	2.54	3.05
Runoff, R (mm/day)	N/A	0.04	0.09
$*dW/dt$	N/A	1.20	0.19
E/P	1.07	0.67	0.92
Potential evaporation, PE (mm/day)	4.90	6.00	5.72
P/PE	0.64	0.63	0.58
$PE - E$	1.54	3.46	2.67

$*dW/dt$: soil moisture change with time ($W = 0$ –200 mm soil moisture).

Regions with larger values of $PE - E$ imply abundance of energy for evaporation, but not enough water available for evaporation, while smaller values imply regions of abundance of water sufficient to satisfy evaporative demand.

In the Northeast, the forest area had higher rainfall, actual evaporation, potential evaporation, local soil moisture, and $PE - E$ and lower runoff than the agriculture

area because forests could contain more soil moistures for evaporation and result in higher rainfall and lower runoff. The urban area located at St. Jones River had the higher evaporation as most of the rainfall was returned to the atmosphere locally by evaporation; hence the ratio of evaporation/rainfall was close to unity. In South Florida,

FIGURE 10: (a) The monthly 0–200 mm soil moisture anomalies in Northeast Florida. (b) The monthly 0–200 mm soil moisture anomalies in South Florida.

hydric soils in wetlands slowly evaporate large volumes of water on surface. Hence, the wetland area had the higher local soil moisture, potential evaporation, rainfall and $PE - E$, but lower evaporation and runoff. In the lake area, evaporation loss exceeded the amount gained from rainfall, and abundance of water was sufficient to satisfy evaporative demand; hence the ratio of evaporation/rainfall (E/R) is close to unity and the value of $PE - E$ is smaller. Moreover, the previous researches showed that annual lake evaporation for the Lake Okeechobee area was approximately 129.5 cm per year (3.54 mm/day) [45]. Waylen and Zorn [46] also presented an annual evaporation estimation map that showed the Lake Okeechobee area with an annual value of approximately 126 cm (3.45 mm/day). Hence, the NARR dataset could provide the valuable analysis for estimating evaporation of Lake Okeechobee.

4.5. Land Use and Land Cover Change in Florida. Florida population has grown from 12.9 million to an estimated 17.4 million residents in 2004, and recent data indicates that almost 80 million tourists visited Florida in 2004. The large numbers of new residents and tourists have resulted

in conversion of both natural and disturbed areas of the Florida landscape to more intensive human uses [47]. The current land-use patterns in the interior, central portion of the Florida peninsula, including extensive mixed agriculture, cities, roads, residential areas, and urban complexes, have collectively supplanted much of the predominantly pine forest areas of the natural landscape.

This rapidly accelerating change in the landscape is associated with a variety of issues, including declining biodiversity [48], climate change and food security, and land degradation as it applies to soils, vegetation, and water. Modeling studies show that summer convection and convergent rainfall in Florida is dependent on land cover, particularly on wetlands, and rainfall has decreased since 1900 as Florida wetlands have been drained [49]. Hence, we have analyzed potential evaporation of North American Land Data Assimilation System (NLDAS-2, <http://www.emc.ncep.noaa.gov/mmb/nldas/>), 0.125 degree hourly primary forcing data on January 1, 1981 and 2000. Figure 11(a) shows the potential evaporation calculated from NLDAS at January 2000, 18 PM. In the afternoon, the potential evaporation was higher in South Florida (land use

FIGURE 11: (a) Potential evaporation calculated from NLDAS at January 1, 2000, 18 PM. (b) Potential evaporation calculated from NLDAS at January 1, 1981, 18 PM.

types: wetland and agriculture areas) and Northeast Florida (land use types: forest and urban areas).

Figure 11(b) shows the potential evaporation calculated from NLDAS at January 1, 1981, 18 PM. In the afternoon, the potential evaporation was higher in Northeast Florida, Central Florida, and South Florida. Comparing to Figures 11(a) and 11(b), in Central Florida, the land use type changed to Pasture/Hay within 20 years. Hence, the land use changes can have an important impact on the water and energy balance and alter relative energy and water vapor fluxes.

5. Summary and Conclusions

Better understanding of the terrestrial water budget on various land uses is necessary and critical for improving our knowledge of current climate, global hydrological cycle, and its dynamics. However, traditional observations, including in situ data and satellite images, have deficiencies in limited long-term records for many hydrologic variables. Moreover, the drawbacks of model-only approaches are that (1) models are not perfectly parameterized and calibrated and (2) models were used in limited land uses like forest, grassland, and agriculture. Hence, in this study, the 1992 to 2002 dataset from North American Regional Reanalysis (NARR) was employed to investigate the water budget on various land uses (lake, wetland, agriculture, forest, and urban) at regional scale in Florida. In Tables 1 and 2, the results showed that Lake Okeechobee and the urban area located at St. Johns River had higher evaporation, lower values of $PE - E$, and E/R ratios closed to 1, while the wetland area had lower evaporation and E/R and higher local soil moisture, PE , and $PE - E$. Moreover, previous studies suggested that evaporation rate measurement at Lake Okeechobee was difficult, but the NARR dataset provided valuable resource for estimating evaporation rate over water bodies. Comparing to the forest and agriculture areas, the tree had the deeper roots, which can sustain more soil moisture, to maintain the higher evaporation and lower the surface runoff.

It was observed that El Niño years tend to be cooler and wetter, while La Niña years tend to be warmer and

drier than the normal in the fall through the spring, with the strongest effect in the winter. Above-normal rainfall was observed on the various land uses during the 1997/1998 EL Niño event, while the negative monthly rainfall anomalies were showed on the various land uses during the 1999/2000 La Niña event. Hurricanes like Andrew and thunderstorms in summer also caused the positive rainfall anomalies more than 70% above normal on the study areas. La Niña drought events and seasonal and interannual variations of climatic variables affect the individual terms of surface water balance on various land uses in Florida. The results showed that, during the drought years, lower average annual precipitation and evaporation were shown on land uses in Florida. The northeast part of the state experienced two dry periods—one is from November to December and the other one is from April to May, while, in South Florida, the dry season occurred continuously from winter through spring.

Soil moisture reflects past precipitation, evaporation, infiltration, and runoff and is related to land surface-atmosphere interactions with the behavior of the boundary layer and precipitation processes. The higher rainfall led to the higher soil moisture and the wetter soil moisture caused an enhanced moisture flux into the atmosphere from the surface, leading to greater specific humidity and precipitation over regions. Hence, the higher soil moisture anomalies were shown from 1992 to May 1998, which resulted in the higher rainfall and evaporation over the forest, agriculture, and wetland areas. Hence, the forest, which had the deeper roots, had lower soil moisture anomalies, but higher evaporation anomalies than agriculture area during the drought event. Moreover, the wetland area had the higher or positive anomalies soil moisture and evaporation during the drought event because wetland can contain and slowly release large volumes of water.

Landscape change is altering convective rainfall and affecting climate. Regional weather patterns are affected by land-use and land cover change. Warm season rainfall should be expected to change whenever deep cumulus convection is common in a region since the surface fluxes of moisture, sensible, and latent heat change [50]. Hence, the land use changes can have an important impact on the water and energy balance and alter relative energy and water vapor fluxes.

Based on these results, the North American Regional Reanalysis (NARR) could provide valuable, independent analysis of the water budget on various land uses in Florida.

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