The Effects of Human Development and Salt Intrusion on the Florida Everglades as it Relates to the Convective Boundary Layer

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ABTRACT:

The Florida Everglades are subject to significant changes in the ecology of the region due to the increased population in Southern Florida. The land is transforming from diverse ecosystems to land used for agriculture or developed urban and suburban areas. This has a lasting impact on the amount of freshwater available for the region. The lack of freshwater is affecting the plant life in the region as saline waters from the Gulf of Mexico are entering the Everglades. The dense mangrove forests in the region struggle to keep up with the significant evapotranspiration occurring and the amount of water vapor in the atmosphere decreases. As a result, the partitioned energy for latent heat decreases where more energy goes into sensible heating of the overall surface layer. This has an impact on the height and water content of the convective boundary layer over the Florida Everglades and a lasting impact on the ecology of the region.

INTRODUCTION:

The Florida Everglades, an ecological wonderland, is known by many to be one of the most beautiful and ecological diverse places in the United States. Sitting in the most southern part of Florida, the Everglades cover 1.5 million acres and are home to thousands of plant and animal species (National Geographic, 2010). The primary plant species in the region are a variety of mangroves species. However, the biome of the Everglades supports approximately 1,000 different plant species. Often times, the Everglades are thought of as a swamp; however, the National Geographic defines this region more correctly as a slow moving river, flowing at about a quarter mile per day (2010). The primary source of water for the region is provided by Lake Okeechobee to the Everglades north and runoff from the abundant rains received during the wet months in Florida. Water flows to the west and drains into the Shark River Slough and to the east into the Taylor Slough. A slough is defined as the deepest region of a marsh ecosystem and home to the most diverse species dotted with tree islands and a wide variety of fish and invertebrates(Everglades Ecology, n.d.).

Over the last several decades, the number of people living in Southern Florida has increased significantly. The overall population in Florida has increased more than 16% since April of 2000 (U.S Census Bureau, 2010). The effects of the increased population in the area are vast and have possible harmful consequences to the delicate ecosystem within the Everglades National Park and surrounding Southern Florida.

With a significant increase in population, the quests for the necessities of human survival threaten to alter the environment in the surrounding regions. The community surrounding Lake Okeechobee and throughout Southern Florida exploded with the population growth of 12.1% since April of 2000 (U.S Census Bureau, 2010). Those living within the watershed fed by Lake Okeechobee continue to draw large amounts of water reducing the amount of water available in the watershed. The stress on the watershed is increasing as more than six million people feed on the freshwater within the watershed with the population expected to double in the next fifty years (National Geographic, 2010). Freshwater often times runs from Lake Okeechobee out through the Everglades and into the Shark River Slough and Taylor Slough along the Gulf of Mexico and the Atlantic Ocean respectively (South Florida Water Management District, 2002).

Figure 1. Map of Southern Florida including Lake Okeechobee, Everglades, Mangrove forest, along with other key features. http://earthobservatory.nasa.gov/Features/DeepFreeze/deep_freeze2.php

However, with an increased population in the region, more water is being used by consumers and freshwater available for flow through the Everglades is decreasing. Water flow patterns over the last several decades have been altered due to the increased human population and the dependence on freshwater (South Florida Water Management District, 2002).

Moreover, agriculture in the region has increases notably in the last few decades. According to the Florida Department of Agricultural and Consumer Services, in 2002, Florida ranked first amongst crop-producing states in amount of citrus crops harvested. They also ranked first or second in total harvests of tomatoes, strawberries, watermelons, bell peppers, radishes, avocados, and sweet corn among others (Florida Department of Agriculture and Consumer Services, 2002). With a large amount of the Everglades being transformed into agricultural lands, the natural water flow of the Everglades is being affected and less water is being introduced into the biome (Pielke, et al., 2007).

I. Effects on the Everglades

The southern Florida peninsula has been subject to many changes over the last 100 years. Widespread changes to topography are occurring with conversions from natural vegetation to urban and suburban developments in the region. With the decrease in freshwater and decrease in the area of the Everglades, the amount of available water for evaporation is on the decline. The region typically receives approximately 127 cm of rainfall per year (Everglades Ecology, n.d.). Much of the rainfall is attributed to strong evaporation and evapotranspiration from plants which is introduced into the convective boundary layer (CBL) and produces significant rains and thunderstorms. These thunderstorms are often times pushed northward from the Everglades due to a strong sea-breeze caused by the water-land temperature contrast. The runoff from these storms flow into Lake Okeechobee and the surrounding watershed. The lake fills during the wet season and excess water flows down the Caloosahatchee River and St. Lucie River or enters the northern extent of the Everglades (Pielke, et al., 1998). However, due to the decrease of available water in the region, the amount of rainfall has decreased by nearly 11% due to the changes to the ecosystem of the Everglades during the twentieth century (Pielke, et al., 1998).

With a decrease in freshwater flow through the Everglades, several harmful feedback processes affect the delicate ecosystem. To replace the lack of freshwater, there is a greater intrusion of salt water into the ecosystem. With less freshwater levels, the mangrove forests which cover much of the Everglades are subject to more saline waters which effect the amount of freshwater they can take up and use in transpiration. As Southern Florida experience average daily temperatures of 27°C from April to October, the extent of evapotranspiration is significant and is the primary mechanism in which water exits the ecosystem (Duever, Meeder, Meeder, & McCollom, 1997). To cope with the strong evapotranspiration and lack of freshwater, mangroves close their stomata aiding in the retention of water. With the primary water source being diminished, the amount of water that enters the CBL is less and the probability of convective thunderstorms during the summer wet season decreases. In turn, the decrease in rainfall only hurts the ecosystem as less freshwater then enters the Everglades resulting in a feedback loop.

METHODS:

In order to diagnose the effects of salt intrusion and human impacts on the Everglades, data was collected for a seven day period starting August 1, 2010 and concluding on August 8, 2010 in a remote location within the Florida Everglades. Using several sensors including a sonic wind anemometer, many quantities within the boundary layer were assessed and computed during this time period. Empirical data such as wind speed (m s^{-1}), wind direction (degrees), solar irradiance (W m^{-2}), and CO_2 flux (mmol m^{-2} s^{-1}) were measured.

Moreover, using the empirical wind data, friction velocity (m s^{-1}) was also computed:

$$u_*{}^2 = [\overline{u'w'} + \overline{v'w'}]^{1/2}$$

where u' indicates the perturbation from the mean wind speed in the u-direction, v' indicates the perturbation from the mean wind speed in the v-direction, w' indicates the perturbation from the mean wind speed in the w-direction, and the overbar represents the average of the two quantities. The friction velocity helps to describe the motion of the eddies in the lower levels of the boundary layer.

In addition, quantities such as sensible heat and latent heat can also be computed. We know that the following relationship exists:

$$R_{net} = H + LE + G$$

where R_{net} is the available energy, H corresponds to heating of the air, LE is the energy partitioned for evaporation of water (both of which can be calculated using eddy covariance and aerodynamic methods), and G corresponds to the soil heat flux. The sensible heating of the air is calculated as

$$H = \bar{\rho} c_p (\overline{w'\theta'})$$

and latent heat can be calculated as

$$LE = \bar{\rho} L_V (\overline{w'q'})$$

where $\bar{\rho}$ is the average air density, c_p is the heat capacity at constant pressure (~1005 J kg^{-1} mol^{-1}), L_V corresponds to the latent heat of vaporization (~2.5 x 10^5 J kg^{-1} K^{-1}), θ' is the perturbation from the mean potential temperature, and q' is the perturbation from the mean specific humidity. In most instances, the soil heat flux (G) is not computed as it is very small or often times negligible.

Moreover, using the data collected, the height of the convective boundary layer can be assessed:

$$z_i^2 = \frac{2}{\gamma_v} \left[(\overline{w'\theta_v'})_{sfc} - (\overline{w'\theta_v'})_{z_i} \right] (t - t_o) + z_i(t_o)$$

In the above equation, z_i corresponds to the height of the CBL. Using the environmental lapse rate (γ_v), kinematic heat flux at the surface, kinematic heat flux at the height of the CBL, the change in time, and the initial height of the CBL, the height of the convective boundary layer can be modeled. In some models, the kinematic heat flux due to encroachment at the height of the CBL is assumed to be zero. However, this is more appropriately estimated by

$$(\overline{w'\theta_v'})_{z_i} = 0.2 * (\overline{w'\theta_v'})_{sfc}$$

The kinematic heat flux at the surface is illustrated by

$$(\overline{w'\theta_v'})_{sfc} = \frac{H_v}{\rho c_p}$$

where

$$H_v = H + .07LE$$

Quantities such as sensible heat (H), latent heat (LE), air density (ρ), and environmental lapse rate (γ_v), are measurable quantities.

RESULTS:

I. Data Collected

The wind speed and direction seem to exhibit a diurnal pattern over the observed time period. This diurnal pattern suggests that the area is affected by a sea-breeze. During the night time, the winds blow from the land towards the sea as the temperature over the water is greater than that over the land. This phenomenon occurs because the water has a higher specific heat and is warmer than the cooler surface over land. The same principle holds true during the day where the land heats up greater than that of the sea and the winds blow from the sea to land.

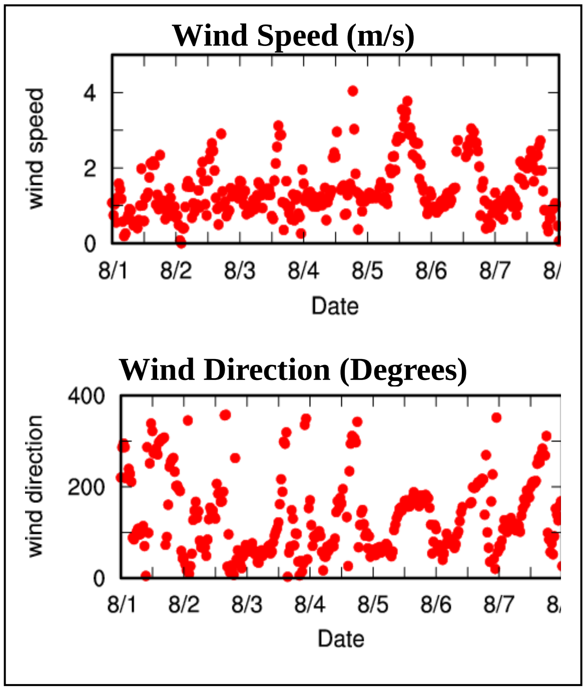


Figure 2. Graphs show diurnal pattern of wind speed and direction resulting from the effects of the land/sea breeze.

The calculated friction velocity which corresponds to the motion of eddies in the surface layer exhibits a diurnal pattern. This is due to the induced convective nature of the boundary layer because of daytime heating.

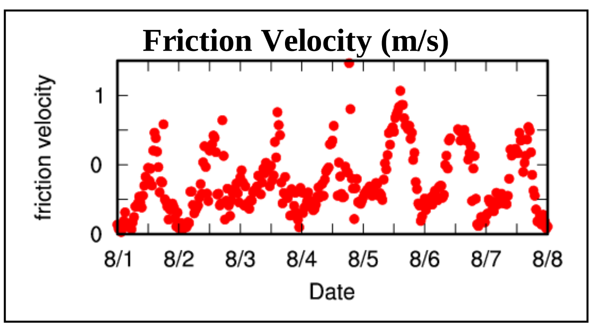


Figure 3. Graph of friction velocity measured in the Florida Everglades from August 1, 2010 through August 8, 2010.

The solar irradiance also exhibits an obvious diurnal effect. The solar irradiance is tied closely with the available energy (R_{net}), latent heat (LE), and sensible heat (H) which also exhibits a diurnal pattern. With a decrease in the amount of water available for evapotranspiration, the amount of water available to contribute to latent heat also decreases. Moreover, a large amount of energy is available for sensible heating of the atmosphere as the amount of energy that goes into evaporation is less.

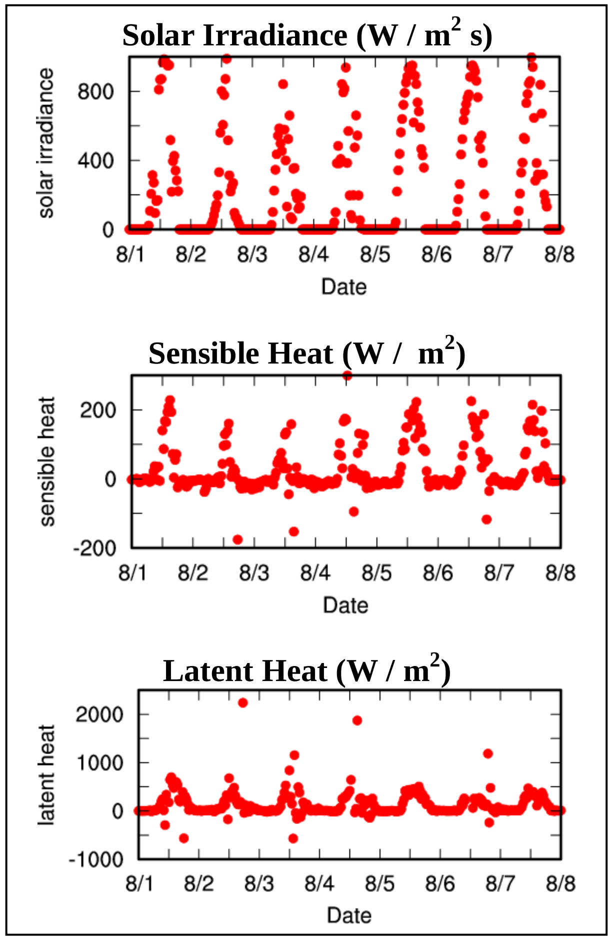


Figure 4. Graphs show the Solar Irradiance, Sensible Heat, and Latent Heat. As the amount of evapotranspiration decreases, the sensible heat increases in the region.

II. Modeling the height of the CBL

The convective boundary layer is modeled using the equation described above. From observed data, the environmental lapse rate on average in the Everglades is approximately 7.3 $^{\circ}\mathrm{C}/_{km}$ (Lonneman, Seila, & Bufalini, 1978). This value is less than the adiabatic lapse rate of 9.8 $^{\circ}\mathrm{C}/_{km}$ but still allows for vertical mixing to throughout the boundary layer. Moreover, the air density is approximated to 1.25 (g kg^{-1}) (Lonneman, Seila, & Bufalini, 1978). Given the above data and these constants, the height of the CBL can be modeled.

Given the effects of human development and salt intrusion into the region, with warmer temperatures, a larger environmental lapse rate, and a less prominent sea-land breeze, the height of the convective boundary layer is greater than that it would be prior to human development and subsequent salt intrusion. To illustrate this, four scenarios were designed which changes the amount of partitioned energy which goes into latent heat and sensible heating.

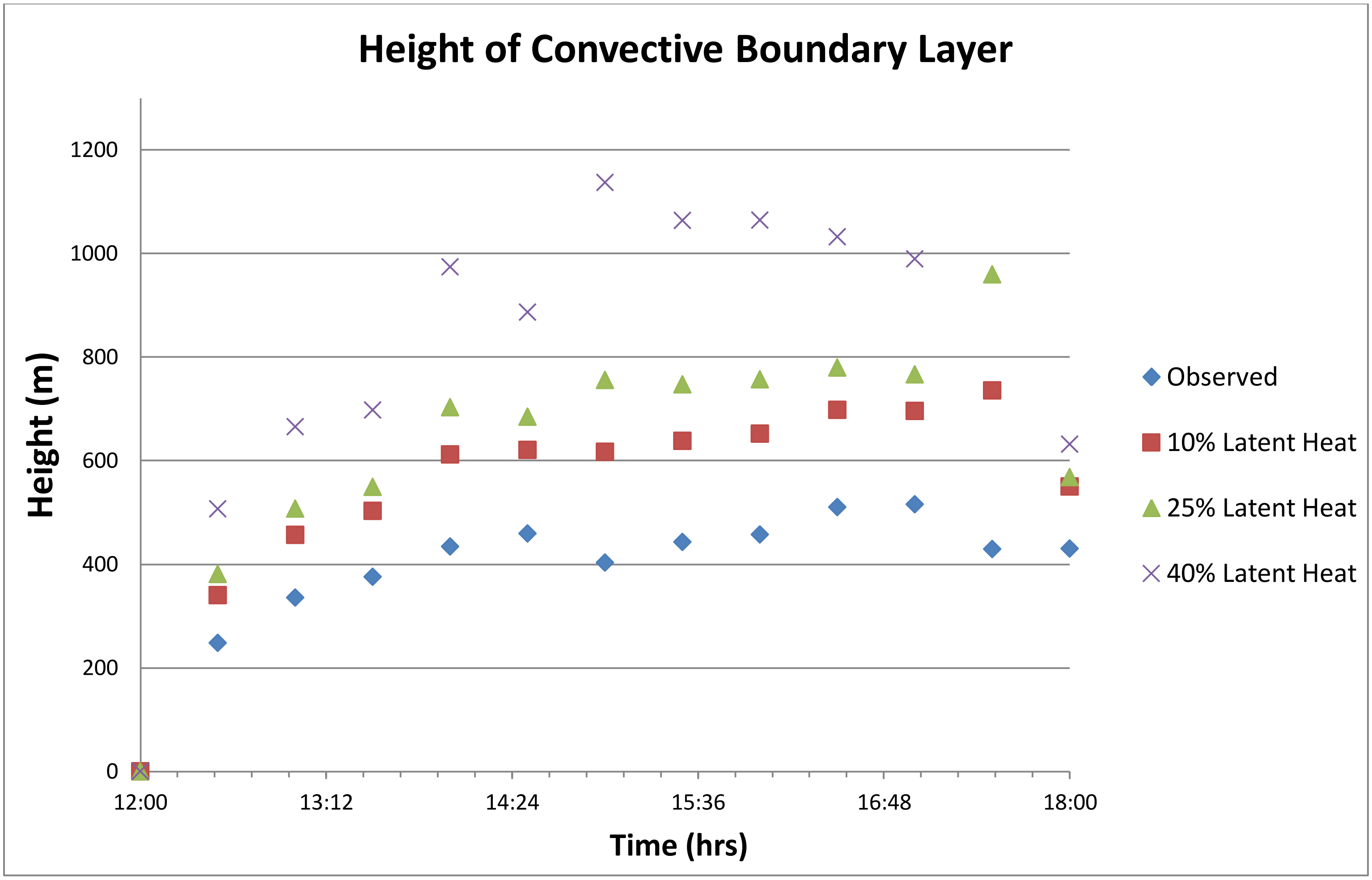
Scenario I: The convective boundary layer modeled using the current observations in the Everglades assuming current values of sensible and latent heat. The amount that the latent heat decreased goes into sensible heating. Based on this value, the height of the CBL is modeled from 12:00hrs to 18:00hrs. The initial height of the CBL is assumed to be zero as the growth of the CBL is minimal when there is a lack of sensible heating during the morning hours. The height modeled based on observed data reaches a max height of 515m during the six hour period.

Scenario II: A decrease in latent heat by 10% of original observed data is modeled. The corresponding height of the CBL is at a max of 735m. A slight decrease in latent heat corresponds to a 200m change in the height of the CBL.

Scenario III: A decrease in latent heat by 25% of original observed data is shown. With a decrease in latent heat and subsequent increase in sensible heat, the height of the CBL at its maximum is approximately 960m.

Scenario IV: A decrease in latent heat by 40% of original observed data is modeled with the maximum in the height of the CBL reaching approximately 1150m.

Figure 4. Height of the Convective Boundary Layer



The graph shows the height of the CBL modeled given the data that was collected August of 2010. The graph illustrates that the given decrease in latent heat corresponds to an increase in the height of the CBL.

Table 1. Scenario I: Height of Convective Boundary Layer Given Observed Data

Time (hrs)	Sensible Heat (W m-2)	Latent Heat (W m-2)	Hv	Kinematic Heat Flux @ Surface (K m s-1)	Kinematic Heat Flux @ Zi (K m s-1)	Height of CBL (m)
12:00	12:00	142.1	483.4	176.0	0.140	0.028
12:30	12:30	165.5	430.0	195.6	0.156	0.031
13:00	13:00	154.0	356.8	179.0	0.143	0.029
13:30	13:30	133.0	237.3	149.6	0.119	0.024
14:00	14:00	119.3	437.4	149.9	0.119	0.024
14:30	14:30	117.0	244.2	134.1	0.107	0.021
15:00	15:00	53.7	463.0	86.1	0.069	0.014
15:30	15:30	67.1	315.1	89.1	0.071	0.014
16:00	16:00	64.3	269.4	83.1	0.066	0.013
16:30	16:30	78.3	195.7	92.0	0.073	0.015
17:00	17:00	74.0	150.7	84.6	0.067	0.013
17:30	17:30	18.0	503.9	53.3	0.042	0.008
18:00	18:00	47.3	24.5	49.0	0.039	0.008

Table 2. Scenario II: Height of Convective Boundary Layer with 10% Decrease in Latent Heat

Time (hrs)	Sensible Heat (W m-2)	Latent Heat (W m-2)	Hv	Kinematic Heat Flux @ Surface (K m s-1)	Kinematic Heat Flux @ Zi (K m s-1)	Height of CBL (m)
12:00	190.5	435.0	220.9	0.275	0.055	0.0
12:30	208.5	387.0	235.6	0.293	0.059	340.2
13:00	189.7	321.2	212.2	0.264	0.053	456.6
13:30	156.7	213.6	171.6	0.214	0.043	502.9
14:00	163.0	393.7	190.6	0.237	0.047	611.9
14:30	141.5	219.8	156.9	0.195	0.039	620.7
15:00	100.0	416.7	129.2	0.161	0.032	617.0
15:30	98.6	283.6	118.4	0.147	0.029	638.2
16:00	91.2	242.5	108.2	0.135	0.027	652.0
16:30	97.9	176.1	110.2	0.137	0.027	698.0
17:00	89.1	135.6	98.6	0.123	0.025	695.9
17:30	68.4	453.5	100.1	0.125	0.025	735.5
18:00	49.8	22.0	51.3	0.064	0.013	550.0

Table 3. Scenario III: Height of Convective Boundary Layer with 25% Decrease in Latent Heat

Time (hrs)	Sensible Heat (W m-2)	Latent Heat (W m-2)	Hv	Kinematic Heat Flux @ Surface (K m s-1)	Kinematic Heat Flux @ Zi (K m s-1)	Height of CBL (m)
12:00	311.3	362.5	336.7	0.419	0.084	0.0
12:30	273.0	322.5	295.5	0.368	0.074	381.0
13:00	243.3	267.6	262.0	0.326	0.065	507.3
13:30	192.3	178.0	204.7	0.255	0.051	549.3
14:00	228.6	328.1	251.6	0.313	0.063	703.0
14:30	178.1	183.2	190.9	0.238	0.048	684.8
15:00	169.5	347.3	193.8	0.241	0.048	755.7
15:30	145.9	236.3	162.4	0.202	0.040	747.2
16:00	131.6	202.1	145.8	0.182	0.036	756.9
16:30	127.2	146.8	137.5	0.171	0.034	779.7
17:00	111.7	113.0	119.6	0.149	0.030	766.5
17:30	144.0	377.9	170.4	0.212	0.042	959.6
18:00	53.5	18.4	54.7	0.068	0.014	568.0

Table 4. Scenario IV: Height of Convective Boundary Layer with 40% Decrease in Latent Heat

Time (hrs)	Sensible Heat (W m-2)	Latent Heat (W m-2)	Hv	Kinematic Heat Flux @ Surface (K m s-1)	Kinematic Heat Flux @ Zi (K m s-1)	Height of CBL (m)
12:00	577.2	217.5	592.4	0.738	0.148	0.0
12:30	509.5	193.5	523.0	0.651	0.130	506.8
13:00	439.5	160.6	450.8	0.561	0.112	665.4
13:30	322.8	106.8	330.3	0.411	0.082	697.6
14:00	469.2	196.8	483.0	0.601	0.120	974.1
14:30	312.4	109.9	320.1	0.399	0.080	886.7
15:00	424.1	208.4	438.7	0.546	0.109	1137.0
15:30	319.1	141.8	329.1	0.410	0.082	1063.7
16:00	279.8	121.2	288.3	0.359	0.072	1064.4
16:30	234.9	88.1	241.0	0.300	0.060	1032.2
17:00	194.6	67.8	199.3	0.248	0.050	989.5
17:30	421.1	226.8	437.0	0.544	0.109	1136.6
18:00	66.9	11.0	67.7	0.084	0.017	631.7

DISCUSSION:

As a result of human development within Southern Florida, the Convective Boundary Layer associated with the Everglades is being impacted. Data analysis comparing the current values attributed to sensible heat and latent heat to past values is needed to better understand the effects of human impacts and salt intrusion into the ecosystem. However, based on theory, we can assume that the amount of energy attributed to latent heat decreases as less evapotranspiration is occurring. As the same amount of available energy exists, the remainder of the energy goes into sensible heating which is responsible for heating of the air. With an increase in sensible heating, the conclusion is that the surface temperature will rise. This will continue to reduce the amount of freshwater available throughout the Everglades.

With an increase in temperature, the height of the Convective Boundary Layer will be greater. As seen, the height of the CBL can increase by than 100% with a significant decrease in latent heat in the environment. Moreover, the extent of water vapor into the CBL is less due to inhibited evapotranspiration. This impacts the frequency and significance of afternoon thunderstorms that were common throughout the wet season in Southern Florida.

It is thought that with the increase in surface temperature, plants will produce greater amount of Biogenic Volatile Organic Compounds (BVOC's) which aid in the formation of harmful atmospheric ozone along with atmospheric aerosols. The production of BVOC's is proportional to temperature where the greater the temperature, the larger the concentration emitted by plants.

Global climate change is also having an impact in the Florida Everglades as the sea level rise is aiding in the saline sea water encroachment into the Everglades.

CONCLUSION:

With the recent development in southern Florida, the human impacts on the ecology of the Florida Everglades will be felt for years to come. Human impacts, such as a decrease of freshwater into the Everglades, are resulting in salt intrusion into the ecosystem, an ecosystem not typically used to prolonged exposure to saline sea water. This is causing a lack of evapotranspiration which is the primary mechanism for water transport into the CBL. With a decrease in water vapor into the CBL, the severity and frequency of rains during the wet season decreases. This effects the replenishment of freshwater into the Florida Everglades. Moreover, the amount of energy partitioned for sensible heat is increased as less energy goes into evaporation. As a result, the air temperature is heated causing an increase in surface temperature. The height of the CBL is directly related to the air temperature and therefore will be higher than it has been in the past. The long-term implications of salt intrusion into the ecosystem and the impacts on plant physiological response are yet to be seen. However, research conclusively finds that the height of the convective boundary will continue to increase given human development and salt encroachment into the Florida Everglades. Significant biological damage is taking place in this ecological gem of the Florida Everglades.

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