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ORIGINAL PAPER

Potential influence of land development patterns on regional climate: a summer case study in the Central Florida

D. W. Shin · Guillermo A. Baigorria

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Abstract Two land development scenarios based on the Central Florida Regional Growth Vision projection for 2050 were used to explore the developments' potential influence on regional climate. One scenario is a widespread suburban land development plan, and the other is a higher density urban development plan, both for the same location in central Florida. A series of simulation experiments were conducted using a regional climate model upgraded for this study to include an urban scheme. Noticeable differences in simulated regional climate patterns were found between the land development scenarios, which could potentially influence population requirements for energy and water. In our simulations, the aggregated effect of land cover changes over large suburban areas produced a more intense heat island effect than that produced by high-density urban areas.

Keywords Urban heat island · Regional model · Land cover change · Regional climate change

1 Introduction

According to the PennDesign study (Barnett et al. 2005), the population of Brevard, Lake, Orange, Osceola, Polk, Seminole, and Volusia counties in Florida (Fig. 1) will increase by 4.2 million people by 2050 (Table 1). In the currently planned suburban land development growth policies (Fig. 2: top panel), 4,798.8 km^2 of land would become urbanized to accommodate the new population. An alternative land development plan (Fig. 2: bottom panel) modifies the current extremely dispersed and inefficient form of development, which could be detrimental to the fragile natural environment, creating a higher density

D. W. Shin (✉)
Center for Ocean-Atmospheric Prediction Studies, Florida State University,
Tallahassee, FL 32306-2840, USA
e-mail: shin@coaps.fsu.edu

G. A. Baigorria
Agricultural & Biological Engineering Department, University of Florida,
Gainesville, FL 32611-0570, USA

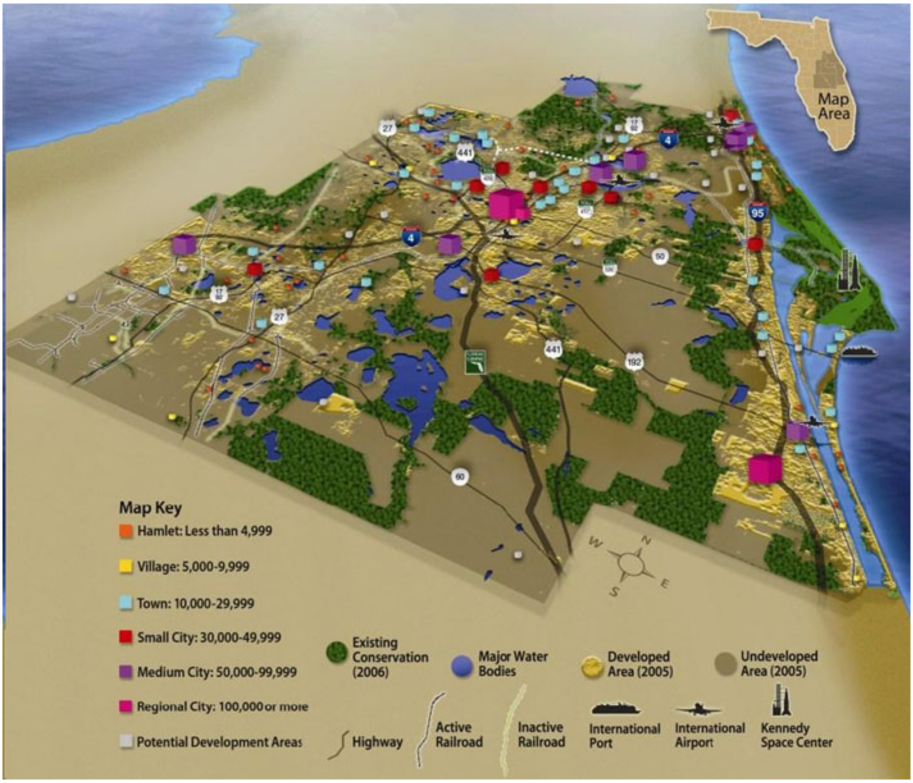


Fig. 1 Central Florida today (courtesy of http://www.myregion.org)

Table 1 Relative growth rate of population and average housing density

County	Population		Average housing density (units km^{-2})
	Current	Growth rate (%)	
Brevard	519,387	9.1	84
Lake	260,788	23.9	42
Orange	989,926	10.4	154
Osceola	219,544	27.3	21
Polk	524,389	8.4	47
Seminole	391,449	7.2	184
Volusia	478,670	8.0	74

development using only 1,701.3 km^2. The alternative urban construction plan, which includes buildings, townhomes, and low-rise apartments, would reduce infrastructure costs, allowing the acquisition of environmentally sensitive land and the transit system needed to support the proposed higher residential densities.

An important question not taken into account in the PennDesign study is how these two land development strategies might affect the regional climate because of the so-called urban heat island (UHI) effect caused by urban development. UHI could potentially increase temperatures (Rosenzweig et al. 2005; Trusilova et al. 2009) and modify the rainfall patterns

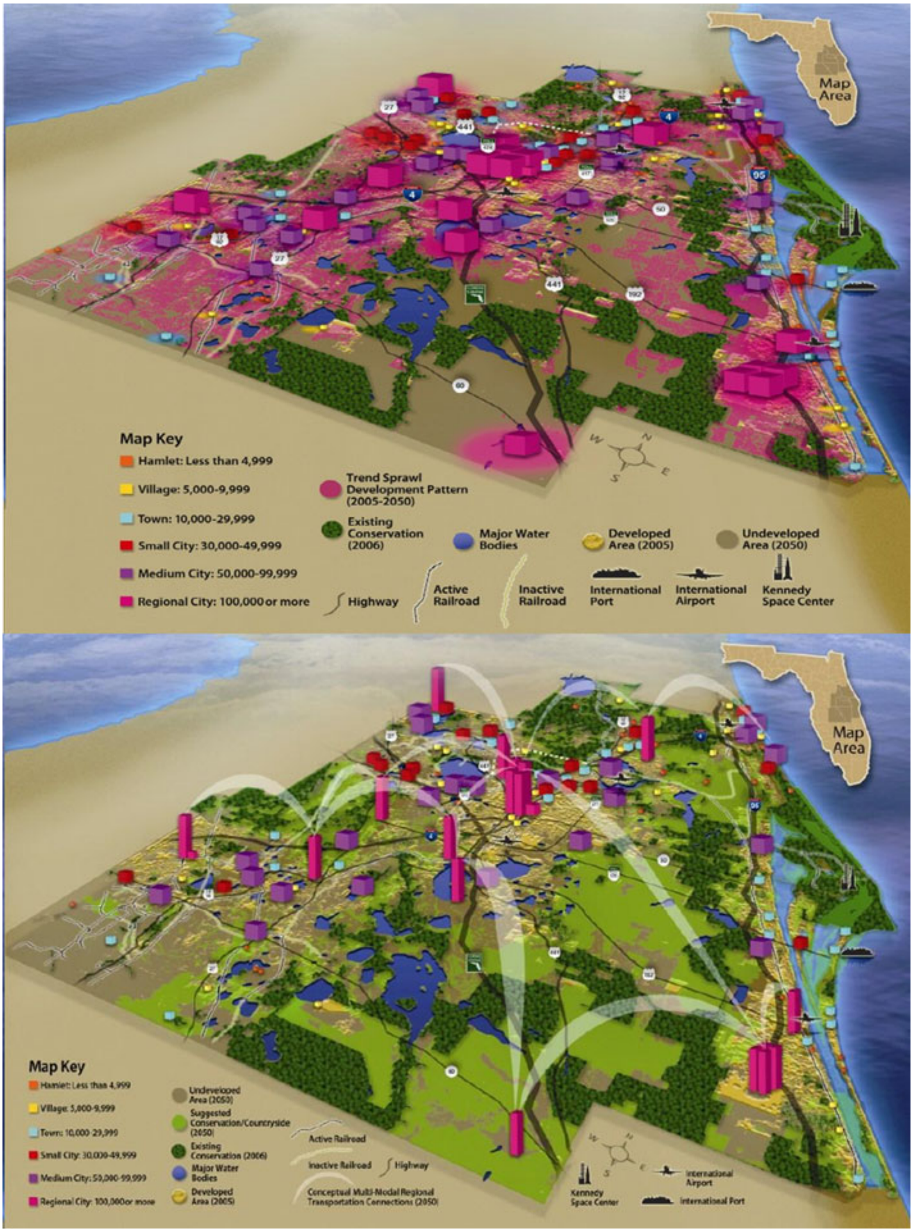


Fig. 2 Central Florida growth scenarios for 2050. *Top panel* the current growth policies; *bottom panel* an alternative growth vision (courtesy of http://www.myregion.org)

(Rozoff et al. 2003; Shepherd 2005; Mote et al. 2007; Hand and Shepherd 2009; Schlünzen et al. 2010) in the area, modifying the amount of energy and water needed by the projected cities under both scenarios (e.g., Pielke and Avissar 1990; Pielke et al. 1999; Marshall et al. 2004; He et al. 2007). Hence, the objectives of this short contribution are (1) to study the potential impacts of both 2050-projected land development strategies on the regional climate and (2) to evaluate the feasibility of using numerical climate models to assess those potential impacts, thus providing valuable information to decision makers.

Scenarios of climate change projections for 2050 are not evaluated in the current study. This paper compares the feedbacks of the current urban areas in central Florida with two different urban development projections under the warmest summer in the region where data were available for regional climate simulations. This study delivers a first idea of which direction of urban development leads to smaller changes in daily minimum air temperature. It is a contribution to land-use change studies concerning impacts on the atmosphere at regional scale.

2 Model

The Florida State University/Center for Ocean-Atmospheric Prediction Studies (FSU/COAPS) regional spectral model coupled to the National Center for Atmospheric Research Community Land Model v.2 (CLM2) (Shin et al. 2005, 2006) is used to include an urban scheme following the study by Jin et al. (2007). Two human-related terms, anthropogenic heat flux and storage heat flux, are added to the surface energy balance equation (Taha 1997; Grimmond and Oke 1999).

$$(1-\alpha)Q_i + L^* - H - \lambda E - G + Q_f - Q_s = 0 \tag{1}$$

where α is albedo; Q_i, incoming solar radiation; L^*, net long wave radiation; H, sensible heat flux; λE, latent heat flux; G, non-urban ground heat flux; Q_f, anthropogenic heat flux; and Q_s, storage heat flux.

The anthropogenic heat flux term is attributed to fuel combustion, air conditioning, and other human activities. This term, which depends on factors such as the intensity of energy use, transportation systems, and power generation, exhibits both seasonal and hourly variations. The storage heat flux term is the net uptake/release of energy by sensible heat changes in the urban canopy air layer, buildings, vegetation, and urban ground. It is calculated as a function of the net all-wave radiative flux (Q^*) weighted by four urban-type areas (A_i): rooftops, impervious, walls, and vegetation (see Table 2).

$$Q_s = \sum_{i=1}^{4} A_i \left(a_i Q^* + b_i \frac{\partial Q^*}{\partial t} + c_i \right) \tag{2}$$

where a_i, b_i, and c_i are empirical coefficients based on the objective hysteresis model (Grimmond and Oke 1999).

3 Experimental designs

The regional model is one-way nested within the FSU/COAPS global climate model at a horizontal resolution of T63 ($\sim$1.87°). Figure 3a shows the current distribution of urban

Table 2 Urban-type area percentage

	Urban-type area (A_i)			
City type	Rooftops (%)	Impervious	Walls	Vegetation
Urban	32	25	42	1
Suburban	29	24	21	26

and preserved areas in the southeast United States along with the regional climate model resolution ($\sim$20 km $\times$ 20 km). The regional model grids over the Gulf of Mexico are not drawn intentionally. Urban areas with city names in Florida are drawn in Fig. 3b in order to identify the location of cities used in this study.

The global climate model is first run for the boreal summer (June–August) of 1998 to produce the boundary conditions for the regional model experiments. Year 1998 (a strong El-Nino year) is selected because it was one of hot years from 1895 to present in Florida (average temperature of 1998, 22.5°C; long-term average temperature, 21.4°C). Hence, we assume that it might represent a future (2050) warm climate environment. After the urban parameterization is included in the FSU/COAPS regional model, two experiments are performed for June–August 1998 using (i) the land surfaces without prescribed urban areas and (ii) land surfaces with the current urban areas in order to evaluate the current UHI effects. In addition, the FSU/COAPS regional model is integrated for the same 3-month period using both 2050-projected land surfaces [(i) the current widespread suburban land development and (ii) the alternative higher density urban development] to assess the potential effect of each growth development strategy. All simulations use observed weekly sea surface temperatures and European Center for Medium-range Weather Forecasting analyses.

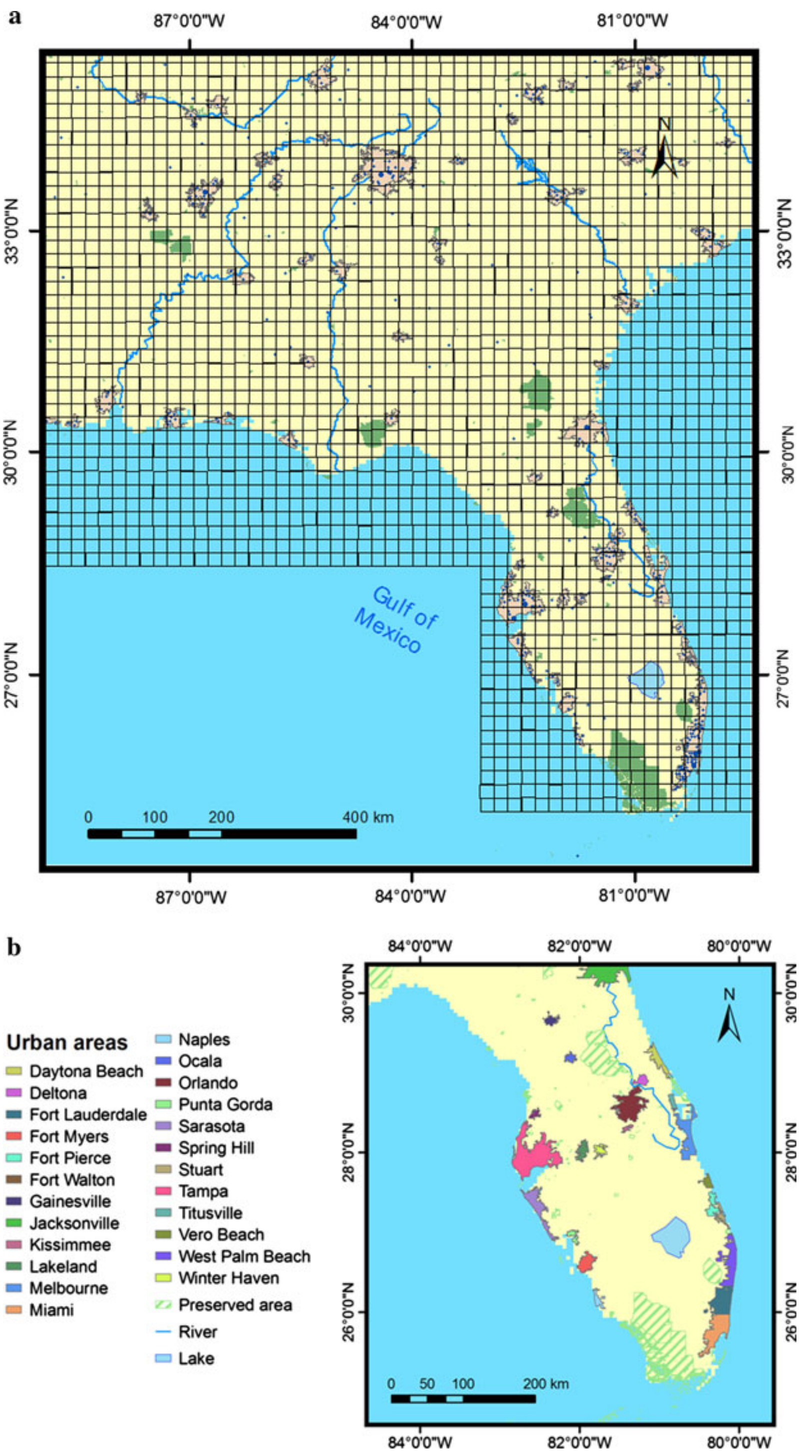
4 Results

4.1 Simulating urban heat island effect

The UHI effect is first evaluated by modifying the land surface types in the FSU/COAPS regional climate model. Two simulations are performed: one simulation uses land surfaces with a non-urban area assumption, and the other uses the current urban information in Florida (Fig. 3b). As expected, including urban information produces significant increments in minimum temperatures over all the urban areas (Fig. 4a). Here, minimum temperature is used because it explains the UHI effect better than maximum and/or average temperature. Strong signals of UHI are shown around Tampa and Jacksonville. Because of the highly stable oceanic influence, the Miami area is less influenced by the UHI. Meanwhile, the changes in rainfall amount and pattern are very small (less than 1% of total rainfall) due to the dominant summertime weather system (e.g., the sea-land breeze) over this area (Fig. 4b). However, reduced rainfall amounts are seen on the west coast of Florida, especially around the Tampa area. There are almost no differences in rainfall in the east coast urban area, perhaps because of the strong west-to-east synoptic weather patterns.

4.2 Two 2050 growth scenario simulations

Our simulation results show that the aggregated effect of highly sparse suburban land developments, which replace vegetated areas in the central Florida region, produces a higher UHI effect (widespread minimum temperature changes) than that produced by the high-density urban areas (Fig. 5). Most likely, the widespread minimum temperature increase from the current growth scenario requires much higher energy to cool the summer night than the localized increase from the alternative growth plan. It should be noted that maximum temperature change (not shown) is also an important concern because it is related with daytime energy consumption (business-related such as office buildings and


a
87°0'0"W
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82°0'0"W
80°0'0"W
30°0'0"N
28°0'0"N
26°0'0"N
N
0 50 100 200 km
Urban areas
Daytona Beach
Deltona
Fort Lauderdale
Fort Myers
Fort Pierce
Fort Walton
Gainesville
Jacksonville
Kissimmee
Lakeland
Melbourne
Miami
Naples
Ocala
Orlando
Punta Gorda
Sarasota
Spring Hill
Stuart
Tampa
Titusville
Vero Beach
West Palm Beach
Winter Haven
Preserved area
River
Lake

◀**Fig. 3** **a** Current distribution of urban and preserved areas in the Southeast United States. The *grid* indicates the horizontal resolution at which the regional climate model performed (~20 × ~20 km). **b** Urban areas with city names in Florida

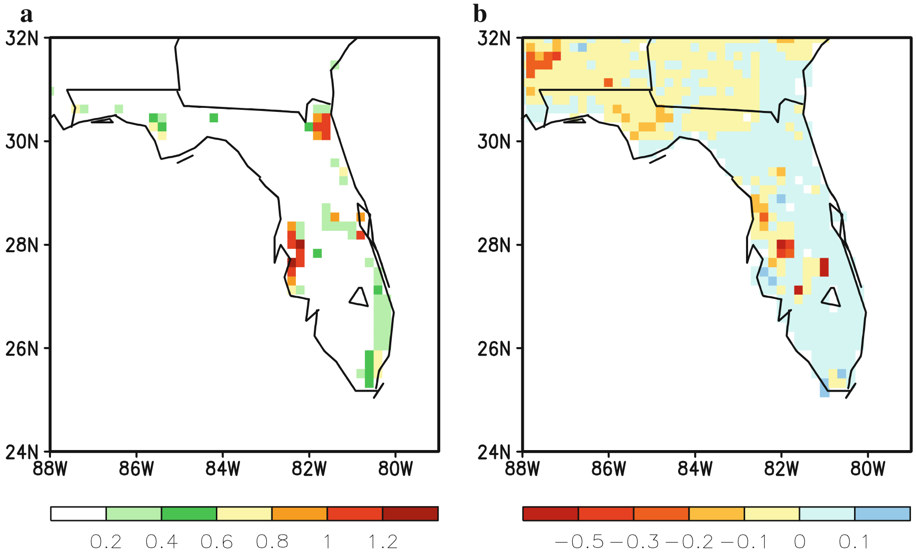

Fig. 4 Simulated differences of **a** minimum temperature (K) and **b** rainfall (mm/day) between the current urban and non-urban land surfaces

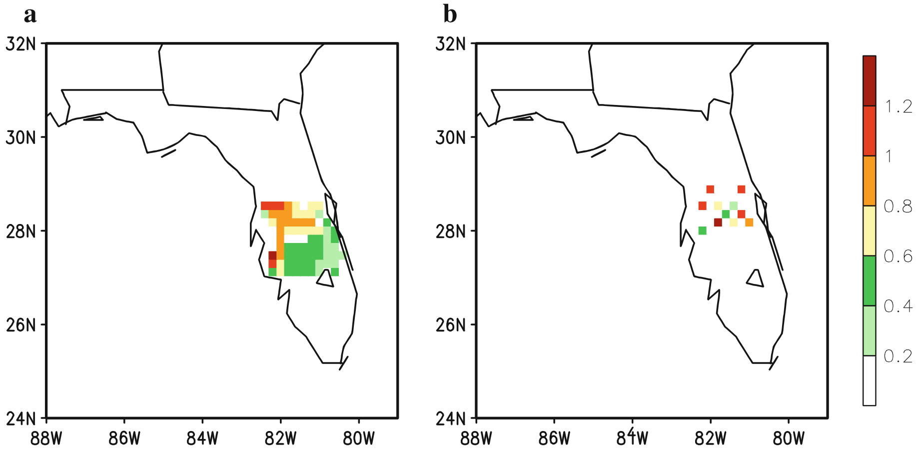

Fig. 5 Simulated increments in minimum temperature (K): 2050-projected land development for two urban growth scenarios, **a** the current growth policies and **b** the alternative growth vision, in relation to the current urban condition

factories) as well as heat-related health issues. Also, in some cases, maximum temperature can affect urban water use. Meanwhile, rainfall patterns and amounts are not significantly modified for both scenarios over this region (not shown). Therefore, for both

2050-projected plans in central Florida, the energy demand might be much higher than the water demand.

5 Conclusions

On the base of the results from this study, the following conclusions can be drawn:

- Urban Heat Island (UHI) effect is highly dependent on the geographical position of the cities in Florida in relation to major water bodies.
- The aggregated effect of large suburban areas produced a higher UHI effect (in terms of minimum temperature) than that produced by the high-density urban areas projected for 2050 in central Florida, because the proposed suburban growth is over a much larger area (i.e., the greater land-use changes) than the assumed urban growth.
- The energy demand might be much higher than the water demand for either development plan projected for 2050 in central Florida. However, the energy demand might also affect urban water use.

Since our experiments are very limited, more comprehensive simulations at a higher resolution, longer period of time (at least a decade) with a more realistic future boundary forcing, an improved urban scheme and/or with other models (such as multi-model ensemble approaches) must be performed before these results can be used in decision-making processes. The role of natural climate variability (such as, the North Atlantic Oscillation and the El-Nino Southern Oscillation) should also be considered to understand the local climate change better. However, this study provides a preliminary guidance for the understanding of the effects land development strategies might have on the regional climate.

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