# SEASONAL VARIABILITY AND TRENDS OF THE MIAMI URBAN HEAT ISLAND

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## 1. INTRODUCTION

Urban areas tend to be consistently warmer than their rural surroundings due to altered evapotranspiration properties (Taha 1997), increased anthropogenic heat output (Oke 1982), and higher heat capacities of urban substrates (Swaid 1991). The induced horizontal temperature gradients associated with urban heat islands (UHIs) are known to influence convection and subsequent mesoscale circulations (Baik et al. 2001), thus having the potential to modify precipitation distribution within, and adjacent to, the urban center (Shepherd et al. 2002, Dixon & Mote 2002, Dou et al. 2013). Aside from confirming its existence (Debbage & Shepherd 2015, Kandel et al. 2016), relatively little work has been conducted on the Miami urban heat island. The city's unique climate and topography further increase the need for such a study. The primary goals of this study largely remain unchanged: to 1. verify the presence of the Miami Urban Heat Island (UHI), 2. assess its strength and variability, and 3. evaluate its potential influence on precipitation distribution in south Florida when considered in relation to convective steering flow. Aside from the incorporation of additional datasets, previously discussed methodology is also retained. This document will discuss the supplementary data sources utilized, expound on previously discussed methodology, and discuss results acquired during Summer/Fall 2017 and Spring 2018.

## 2. METHODOLOGY

### 2.1 *Additional Data Sets*

Several additional datasets have been incorporated into our analysis. Additions were made in an effort to diversify data sources, bolster confidence in current findings, and to assist in formulating hypotheses for observed results. These datasets include gridded satellite-derived land surface temperatures (LSTs), gridded precipitation estimates of varying spatial resolutions and methods of acquisition, and gridded multilevel wind regimes for the period of 2002-2011. Monthly-averaged satellite-derived LSTs were acquired from the Moderate Resolution Imaging Spectroradiometer (MODIS) operating on the Terra and Aqua satellites. Use of satellite-derived LSTs prevents the introduction of artificial biases in derived UHI intensity that result from variability of surface station environments such as site layout, soil and atmospheric moisture, and topography. These biases are of paramount concern as direct comparisons were made between surface station temperature data from urban and rural sites that likely exhibit inherent differences, particularly in soil moisture content. Additionally, use of LSTs provides a fundamentally different interpretation of UHI intensity and can more adequately speak to differences in surface heat storage than can 2-m temperatures recorded by surface stations.

Two additional precipitation data sources have been incorporated in an effort to diversify observations and increase confidence. These additions were made out of an abundance of caution, due to mild skepticism in the practicality of our original precipitation data source. Our primary precipitation dataset originated from surface stations operated by the National Centers for Environmental Information (NCEI) and National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program that were then interpolated by the Livneh Research Group at the University of Colorado Boulder to form a spatially contiguous .06° x .06° grid of temperature, precipitation, and surface flux data (hereby referenced as Livneh). It was chosen primarily due to its high spatial resolution and agreeable period of record. However, assessment of the spatial contiguity of the surface stations utilized for interpolation casted doubts as to its practicality for such small-scale precipitation analysis. Irregular surface station density favoring urban Miami may act to artificially enhance or skew the urban-associated precipitation maxima noted in preliminary observations. However, the extent to which this may occur is unknown. Nonetheless, alternatives were sought due to these revelations. To remedy this, gridded 2 km x 2 km precipitation estimates derived from Next Generation Radar (NEXRAD) were acquired from the South Florida Water Management District (SFWMD) for the analysis period. This data is of higher resolution (~2 km vs. ~6 km) and higher confidence as it is assessed against SFWMD rain gauge data prior to distribution. Daily gridded precipitation data was also acquired from the North American Regional Reanalysis (NARR) Project. This dataset, while of lower spatial resolution (.3°, ~32 km), adds an additional and fundamentally different data type by virtue of its nature as reanalysis.

Daily and monthly lower-midlevel (surface and ~900-700 hPa) wind velocity data is also incorporated to serve a twofold purpose. Daily/monthly average wind

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velocity is primarily employed to corroborate previous UHI studies, which convey a strong correlation between UHI intensity and wind velocity (higher wind speeds act to minimize urban-rural temperature differences through advection) (Kim & Baik 2005). Additionally, wind velocity data is utilized to assess the potential influence of mesoscale steering flow in modulating the position of precipitation maxima relative to the urban center. This data is also acquired from the NARR Project, in line with previous UHI-precipitation investigations that employed similar reanalysis datasets. Several previous studies have shown that precipitation maxima typically occur downwind of the urban center and can vary in orientation and proximity based on predominant steering flow (Shepherd et al. 2002, Dixon & Mote 2002, Dou et al. 2013). Incorporation of this dataset into our analysis will ideally enable further validation of the aforementioned statements. Initially, wind velocity data from the National Centers for Environmental Prediction (NCEP) Reanalysis Project was selected. However, coarse spatial resolution (2.5°) and the unique shape of the Miami urban area necessitated a finer resolution dataset.

### 2.2 *Analysis Strategy*

The methodology briefly described in previous documentation remains intact. Analysis of urban-rural daily minimum temperatures, monthly average urban-rural LSTs, and daily/monthly UHI intensity acts as the foundation for this study. Four NCEI surface stations were selected from urban and rural representative regions. The four urban surface stations are predominantly concentrated slightly north of downtown Miami (Miami International Airport, Opa Locka Executive Airport, Hialeah, Miami Beach) whereas the four rural surface stations are spread over a portion of central south Florida (Ten Mile Corner, Raccoon Point, Oasis Ranger Station, Ochopee). As a result of the relative lack of surface stations in what is considered rural south Florida, our selection of rural representative surface stations was overwhelmingly constrained by favorable overlapping period of record. Daily minimum temperatures were averaged for the four urban and four rural stations, respectively. As previously stated, the daily minimum temperature difference between designated urban and rural representative regions is employed as the primary working proxy for UHI intensity (defined as $T_{min,urban} - T_{min,rural}$). Daily urban-rural minimum temperatures are analyzed on yearly and seasonal timescales. Daily UHI intensities are then categorized as strong (>2.78° C), average (2.28° C-2.78° C), weak (0° C-2.28° C) or negative (<0° C) (referred to as "urban cool islands") for use in wind/precipitation analysis.

Similar quantitative temperature analysis is performed on gridded Livneh daily minimum temperature data and MODIS monthly average LST data in an effort to assess the accuracy of NCEI-derived UHI intensity. Urban and rural representative grids are defined for this quantitative analysis. The east/west boundaries of the urban representative region are defined using the coordinate definition of urban Miami as established by the US Census. Due to its unusual shape compared to typical landlocked urban regions, northern and southern borders are designated as 26° N and 25.5° N in an effort to retain the primary essence of this analysis (immediate urban "Miami" as opposed to the Census definition of urban Miami). The rural representative region is defined as a polygon with vertices that include each of the four rural NCEI surface stations, to more easily assess the accuracy of NCEI-derived temperature analysis.

### 2.3 *Analysis in Progress*

Correlative analysis is currently being conducted to assess the dependence of UHI intensity on wind velocity and precipitation distribution. Correlative analysis will also be performed to assess the dependence of precipitation distribution on UHI intensity and predominant convective steering flow.

Daily gridded precipitation data (Livneh, NARR, and SFWMD) is first compiled on monthly, yearly, and seasonal timescales to assess climatological precipitation distribution in south Florida. These temporal intervals will be compared against observed precipitation climatology provided by the PRISM Climate Group to assess the climatic validity of our analysis period. The various precipitation datasets will then be filtered based on each day's derived UHI intensity. This is done to assess distribution of precipitation on days of varying UHI intensity. The same analysis will be performed for days directly following each UHI day, as previous research has shown that nocturnal UHIs may act to precondition the subsequent day's atmospheric environment. A similar data aggregation strategy and analysis technique will be utilized when analyzing daily UHI intensity and average wind velocity.

Through preliminary investigation of precipitation data, it was found that the observed dominant seasonal variability in UHI intensity produces an artificial seasonal alias in precipitation distribution. As a result, UHI intensity-based precipitation analysis will be further constrained by month and season in an attempt to remove the seasonal precipitation variability signal. At this juncture, validated precipitation analysis has not been fully completed. However, a precipitation maximum is observed slightly to the west of downtown Miami after assessment of the complete analysis period using both Livneh and NARR precipitation data. Several factors may influence this, including surface convergence and atmospheric instability induced by the UHI. Unfortunately, the magnitude of other potential influences (aerosols, increased surface roughness, etc.) is beyond the scope of this study. Analysis of NEXRAD-derived SFWMD precipitation data will act to further elucidate this potential urban-associated precipitation maximum.

## 3. RESULTS & DISCUSSION

As the results of our NCEI-derived temperature/UHI analysis comprised the focus of the poster presentation, they will not be discussed in this document. With that said, temperature/UHI analysis acquired from Livneh and MODIS datasets will be discussed below and compared against NCEI-derived results.

### 3.1 *Further Urban-Rural Temperature Analysis*

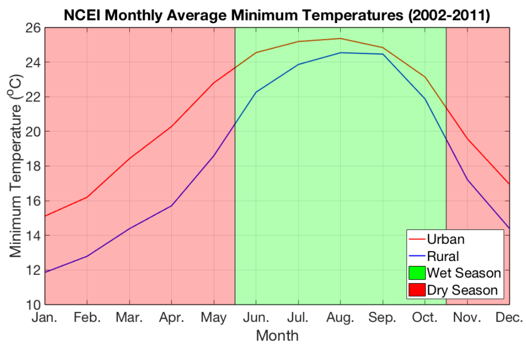


Fig. 1: NCEI monthly average minimum temperatures over the period of 2002-2011. Urban minimum temperatures are in red and rural minimum temperatures are in blue. Approximate durations of south Florida's distinct wet (green) and dry (red) seasons are also included.

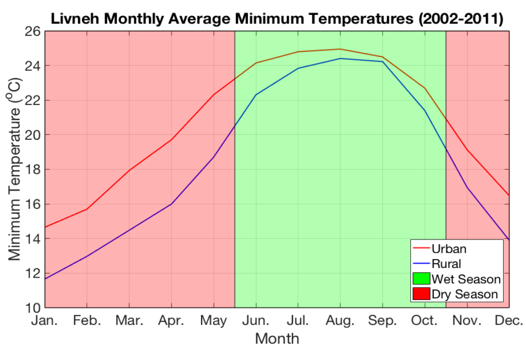


Fig. 2: Livneh monthly average minimum temperatures over the period of 2002-2011. Urban minimum temperatures are in red and rural minimum temperatures are in blue. Approximate durations of south Florida's distinct wet (green) and dry (red) seasons are also included.

Annual minimum temperature behavior can be observed in Fig. 1 and Fig. 2 above. It is clear that minimum temperatures peak in the summer/wet season and reach minima in the dry/winter months. Rural minimum temperatures exhibit a larger annual range than do urban minimum temperatures (+2° C). This is to be expected as the greater heat retention of urban substrates leads to less overall heat flux variability and a subsequently smaller temperature range. Much larger soil moisture variability of rural soils may also play a role in this difference in annual minimum temperature variability. In comparing urban-rural minimum temperatures from NCEI surface stations and the Livneh dataset, it is readily apparent that the Livneh dataset accurately represents the temperatures recorded at the surrounding NCEI/COOP surface stations. The Livneh dataset slightly underestimates daily rural minimum temperatures by .10° C and underestimates daily urban minimum temperatures by .45° C over the complete analysis period. The accuracy of Livneh urban-rural temperature observations is expected as the dataset utilizes NCEI and NOAA COOP surface station observations as its primary source for interpolation. Qualitatively, one can gain a preliminary understanding of seasonal UHI intensity variability by making note of the distance between corresponding urban-rural monthly average minimum temperatures.

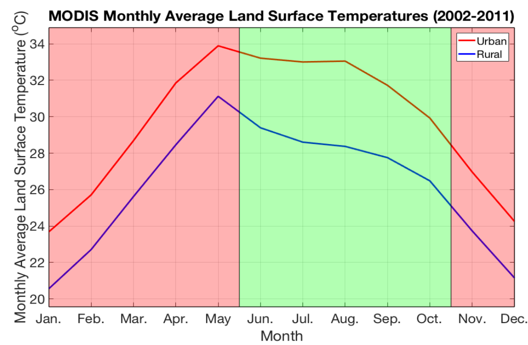


Fig. 3: MODIS/Terra monthly average land surface temperatures over the period of 2002-2011. Urban minimum temperatures are in red and rural minimum temperatures are in blue. Approximate durations of south Florida's distinct wet (green) and dry (red) seasons are also included.

Annual behavior of monthly average LSTs as observed by MODIS/Terra is depicted in Fig. 3 above. It is clear that the magnitude and behavior of LSTs is inherently different than that of observed 2-m minimum temperatures. This is understandable as the mechanisms that modulate LSTs and 2-m temperatures are related but fundamentally distinct. It can be observed that monthly average urban-rural LSTs peak in May (as opposed to Aug./Sep.) and almost seem to exhibit a second, but smaller, maxima during the wet season. MODIS LSTs also exhibit a much smaller annual temperature range (10-11° C vs. 20-25° C) than do surface station 2-m temperatures. This is intuitive as earth's surface retains far more heat than does the atmospheric boundary layer, leading to smaller overall annual LST ranges. Again, observing the distance between corresponding urban-rural monthly average LSTs can afford one a preliminary understanding of the Miami UHI through the lens of satellite-derived LSTs rather than observed 2-m temperatures.

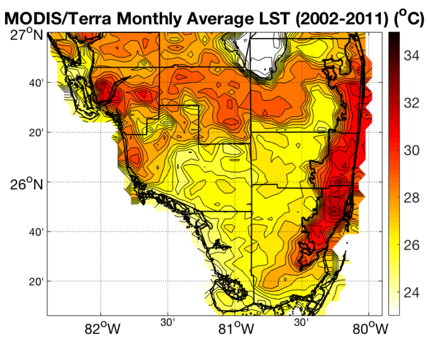


Fig. 4: MODIS/Terra monthly average land surface temperatures over the period of 2002-2011. Census-defined urban Miami is outlined in dark black.

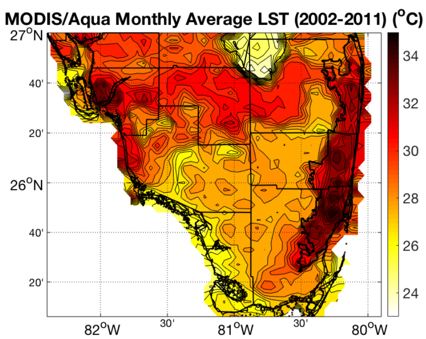


Fig. 5: MODIS/Aqua monthly average land surface temperatures over the period of 2002-2011. Census-defined urban Miami is outlined in dark black.

One can further observe this marked urban-rural LST gradient in Figs 4 & 5 above. Fig. 4 depicts LSTs as observed from the Terra satellite (crosses equator at 10:30 AM local) whereas Fig. 5 depicts LSTs as observed from the Aqua satellite (crosses the equator at 1:30 PM local). By taking both figures into consideration, one can observe the diurnal development of a robust LST maxima collocated with the densest region of urban Miami. Based on NCEI-derived urban-rural minimum temperature differences, Livneh-derived urban-rural minimum temperature differences, and MODIS-derived urban-rural LST differences, it is readily apparent that urban Miami behaves as a UHI and that the magnitude of said UHI varies significantly throughout any given year. Further UHI analysis not included in the poster presentation is described below.

### 3.2 *Miami Urban Heat Island: Seasonal/Interannual Variability & Long-term Trends*

After establishing the presence of a UHI in urban Miami, we then quantify its magnitude and behavior using each of the temperature datasets referenced above (NCEI, Livneh, and MODIS).

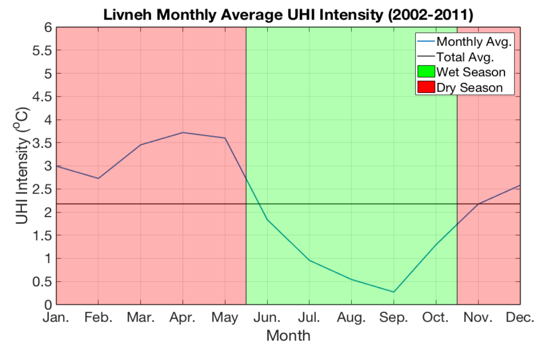


Fig. 6: Livneh monthly average UHI intensity over the period of 2002-2011. Monthly average UHI intensity is in blue and total 2002-2011 average UHI intensity is in black. Approximate durations of south Florida's distinct wet (green) and dry (red) seasons are also included.

In terms of Livneh daily minimum temperatures, urban Miami is observed to remain, on average, 2.23° C warmer than the surrounding region over the complete analysis period. This corroborates the 2002-2011 daily average UHI intensity derived from NCEI surface station 2-m minimum temperature observations (+2.53° C) discussed in the poster presentation. Livneh-derived monthly average UHI intensities exhibit a similar seasonal cycle to that observed in NCEI-derived UHI intensities (Fig. 6). Livneh-derived UHI intensities similarly peak near the end of the dry season (March/April/May) and then decrease markedly during the wet season (reaching a minimum in September. As previously discussed, this is likely the result of soil moisture modulation of near-surface temperatures. A moister rural surface will moisten the boundary layer, resulting in increased downward longwave radiative flux. This increased downward longwave radiative flux may act to mitigate nocturnal rural cooling, thus resulting in a smaller UHI intensity. This hypothesis is supported by the previously stated observation that rural minimum temperatures exhibit a larger annual temperature range than do urban minimum temperatures.

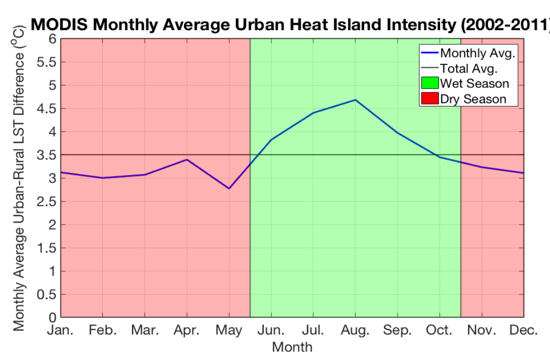


Fig. 7: MODIS monthly average UHI intensity over the period of 2002-2011. Monthly average UHI intensity is in blue and total 2002-2011 average UHI intensity is in black. Approximate durations of south Florida's distinct wet (green) and dry (red) seasons are also included.

The magnitude and behavior of MODIS-derived UHI intensity is fundamentally different than that of 2-m temperature-derived UHI intensities. This is understandable as 2-m temperatures and LSTs react slightly differently to changes in meteorological variables and surface variables. In terms of MODIS monthly average LSTs, urban Miami is observed to remain, on average, 3.50° C warmer than the surrounding region over the complete analysis period. MODIS-derived UHI intensity peaks in Aug, during the wet season (unlike NCEI and Livneh), and exhibits much smaller annual variability than does NCEI/Livneh-derived UHI intensity. Explicit reasoning for this behavior is not currently known, but one may hypothesize that less variability is present as a result of rural MODIS LSTs exhibiting less annual variability than do NCEI/Livneh rural minimum temperatures. As a result of this marked difference in UHI behavior, one must consider UHI intensities derived from 2-m minimum temperatures and LSTs separately.

In addition to distinct seasonal variability, distinct positive trends in several key variables can be observed over the entire analysis period. From 2002-2011, it is observed that monthly urban minimum temperature anomalies increase at a faster rate than do rural minimum temperature anomalies. This is in line with past research which states that temperatures in urban regions will respond more aggressively to a warming climate than will rural temperatures (Oleson 2012). Fig. 8 illustrates the above statement.

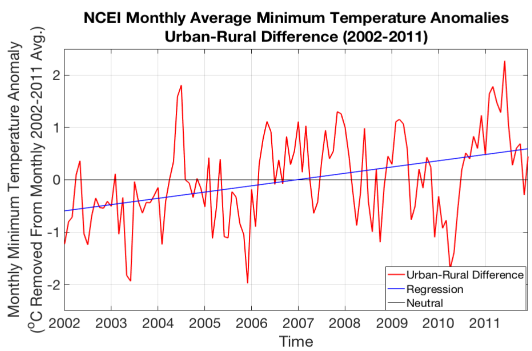


Fig. 8: Difference in monthly urban/rural temperature anomalies over the period of 2002-2011 (red). The overall 2002-2011 trend in urban/rural temperature anomaly difference is depicted in blue. A neutral line at 0 is depicted in black.

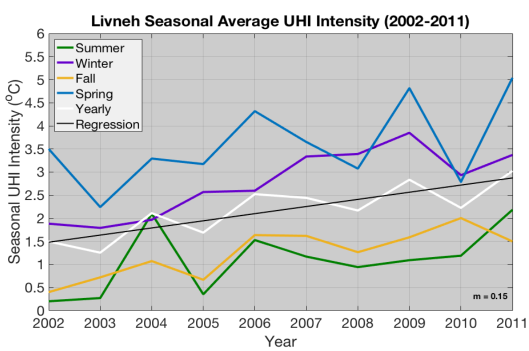


Fig. 9: Livneh yearly average seasonal/overall UHI intensity over the period of 2002-2011. Yearly average UHI intensity is in white (its trend is in black), average summer UHI intensity is in green, average winter UHI intensity is in purple, average fall UHI intensity is in amber, and average spring UHI intensity is in white.

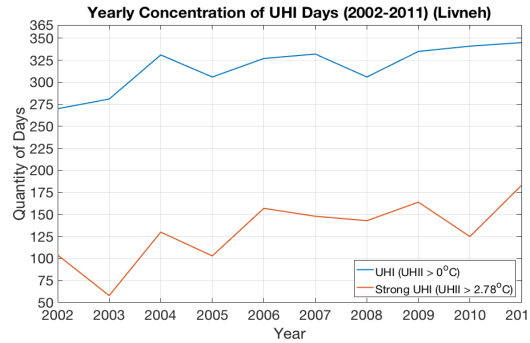


Fig. 10: Livneh yearly average concentration of UHI days (UHII > 0° C, blue) and yearly average concentration of strong UHI days (UHII > 2.78° C, orange) over the period of 2002-2011.

Several key observations can be gained from Figs. 9 & 10. Chiefly, while interannual variability is present, we observe significant positive trends in yearly average UHI intensity and seasonal average UHI intensity over the analysis period. Additionally, we observe a significant increase in UHI days (+70 days) and a significant increase in strong UHI days (+50 days) over the complete analysis period. This may be the result of decadal/multidecadal climatic oscillations that influence local temperature and precipitation distribution. It may also be the result of increases in urbanization and population size in addition to the potential influence of warming as a result of anthropogenic climate change. However, validation of these hypotheses is beyond the scope of this study.

## 4. CONCLUSION

In summary, this study corroborates and quantifies the presence of the Miami UHI through analysis of multiple datasets of diverse origin and acquisition method. Additionally, this study elucidates distinct seasonal variation in UHI intensity (UHI intensity greatest in winter/spring, lowest in fall/summer) and hypothesizes that this may be the result of soil moisture modulation of near-surface temperatures. Furthermore, it is observed that average UHI intensity and concentration of UHI days increase across all seasons over the analysis period. This is supported by the finding that urban minimum temperature anomalies increase at a larger rate than do rural minimum temperature anomalies over the analysis period.

A greater understanding of urban meteorological phenomena, including UHIs and UHI-initiated precipitation, is imperative for a comprehensive assessment of how urban regions impact meteorological environments at the mesoscale level and vice versa. The results of this study will ideally assist in improving urban planning and water resource management for the city of Miami and have potential applications for other coastal urban environments. Furthermore, the importance of such a study will only increase over time, given that humans continue to migrate to urban areas and anthropogenic climate change is predicted to increase the frequency and intensity of heat-related extremes.

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