IMPACT OF URBAN VEGETATION ON THERMAL COMFORT IN THE TROPICAL COASTAL CITY OF FORTALEZA

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ABSTRACT

The thermal comfort in cities is closely dependent on the urban physiography characteristics. In addition to the urban heat island effect, the predicted increase in air temperature as a result of climate change leads to the importance of defining and implementing effective adaptation plans to make cities more pleasant to live in. In this context, we focus on understanding how climate and urban physiography affect human thermal conform, to provide useful information towards a more sustainable urban planning in a climate change context in tropical cities. In this study, the dynamical downscaling up to 1km resolution over Fortaleza city was performed with the convective-permitting regional model HARMONIE-Climate (HCLIMcy38), forced by ERA5 boundary conditions. HCLIM embraces the land surface model SURFEX to simulate urban surface fluxes. The urban physiography is described by the Local Climate Zones and ECOCLIMAP databases. HCLIM modelling outcomes as well as meteorological data from five recent-past years representing assorted climate conditions are used to study different intra-urban microclimates based on different land uses (e.g. parks and residential areas). Additionally, air temperature and relative humidity observations from a measurement campaign with 14 low-cost sensors spread through the city complement the analysis with more detailed local information. Three different environments within the urban area of Fortaleza are taken as example: built-up area, mainly compact high-rise; Urban forest and Lake. The results show that during the wet season, the built-up area is under moderate heat stress during all day, while both urban forest and lake vary from moderate at night to strong heat stress during the sun-light hours. On the other hand, during the dry season, all environments present a similar curve, with thermal comfort indexes varying from moderate to strong heat stress during sun-light hours and no heat stress in the night. The analysis thermal comfort indexes can provide valuable information to urban planners on how people perceive the heat, on where to place new residential areas and how to plan new or recover existent parks in tropical cities.

Keywords: human thermal comfort, urban physiography, tropical cities, dynamic downscaling.

1. INTRODUCTION

The human exposure to heat events is recognized as a trigger to diverse health hazards leading to increase the risk of morbidity and mortality. Urban areas and their dwellers are especially vulnerable to heat events that are predicted to increase in frequency and intensity. The impacts of heat events on human health are largely dependent on how the city is designed in terms of buildings, the thermal properties of urban surfaces (roofs, walls and ground), the presence of water, and vegetation coverage. With an ongoing change towards an even warmer climate, tropical cities in Brazil need to plan to reduce as much as possible the heat stress to which the population is and will be exposed. Green infrastructure is becoming an established component of urban planning and is internationally recognized as an important contribution to ecological and urban sustainability, while make cities more pleasant to live and therefore increase the value of the city/neighborhood. However, most of the research done on the effects of greening cities is focused on medium to high latitudes. The aim of the bilateral cooperation between the Swedish Meteorological and Hydrological Institute (SMHI) and the Federal University of Ceará (UFC) is to produce rational information based on state-of-the-art models and measurements to provide decision makers with a better basis for achieving a future urban environment adapted to an upcoming warmer climate that potentiates the urban resilience and positively contributes to a healthier and fairer society.

2. OBJECTIVE

The aim of this paper is to advance knowledge on the binomial urban climate/urban physiography to provide useful information to a more sustainable urban planning in a climate change context in tropical cities, with a special focus on heat and the effects of green areas on human thermal comfort. Fortaleza, a coastal tropical city in Brazil is taken as case study.

3. METHODS

This study is supported by two types of data sources: 1) modelling data and 2) observations. The modelling data is obtained by dynamical downscaling up to 1km resolution over Fortaleza city, performed with the convective-permitting regional model HARMONIE-Climate (HCLIM; BELUŠIĆ ET AL., 2020; LIND ET AL., 2020; LINDSTEDT ET AL., 2015). HCLIM is a spectral limited area model aimed for the convection permitting scales (~1km) and has been developed to use the full non-hydrostatic equations. The model physical parameterizations (radiation, surface, thermodynamic adjustment, cloud-cover, cloud-microphysics, turbulence and shallow convection) are based on AROME (SEITY ET AL., 2011). The land surface model used is SURFEX (MASSON ET AL., 2013), which is coupled to HCLIM. The SURFEX models of special interest in this context are the Town Energy Balance (TEB, MASSON, 2000) and the Interaction Soil-Biosphere-Atmosphere model with a diffusion soil scheme (BOONE ET AL., 1999) on soil and vegetation. Furthermore, SURFEX employs a dedicated model for oceans and lakes.

A chain of three domains (Figure 1) centred in the city of Fortaleza was designed. The parent domain (TC12) has a horizontal resolution of 12km and 200 × 200 grid cells, and gets the boundary and initial conditions from the ERA5-reanalisys dataset (HERSBACH ET AL., 2020) from ECMWF, at 31km horizontal resolution and on a 3h-basis. TC12 gives the initial and boundary data to the intermediate domain (TC2.5) with 360 × 500 grid cells and 2.5 km of horizontal resolution. The finest domain (TC1) covers a larger area than the Fortaleza metropolitan area with a 1 km × 1 km cell size and 180 × 250 grid cells. All the domains extend over the Atlantic Ocean so that the dominant winds from N and NE are attended. Vertically, the domains are described by 65 layers up to 100 hPa. The lowest layer of the domain is about 12 m thick above the ground.

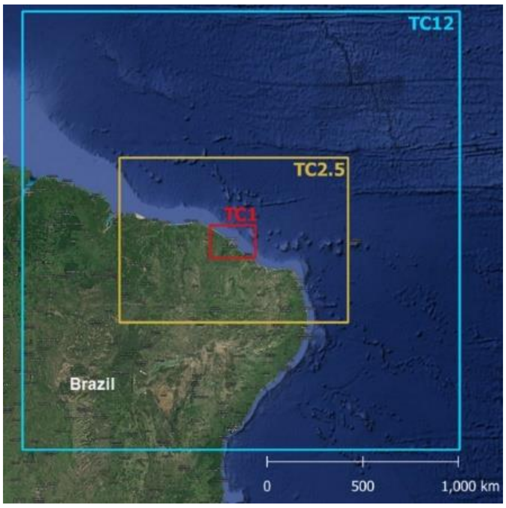

Figure 1 - Simulation domains.

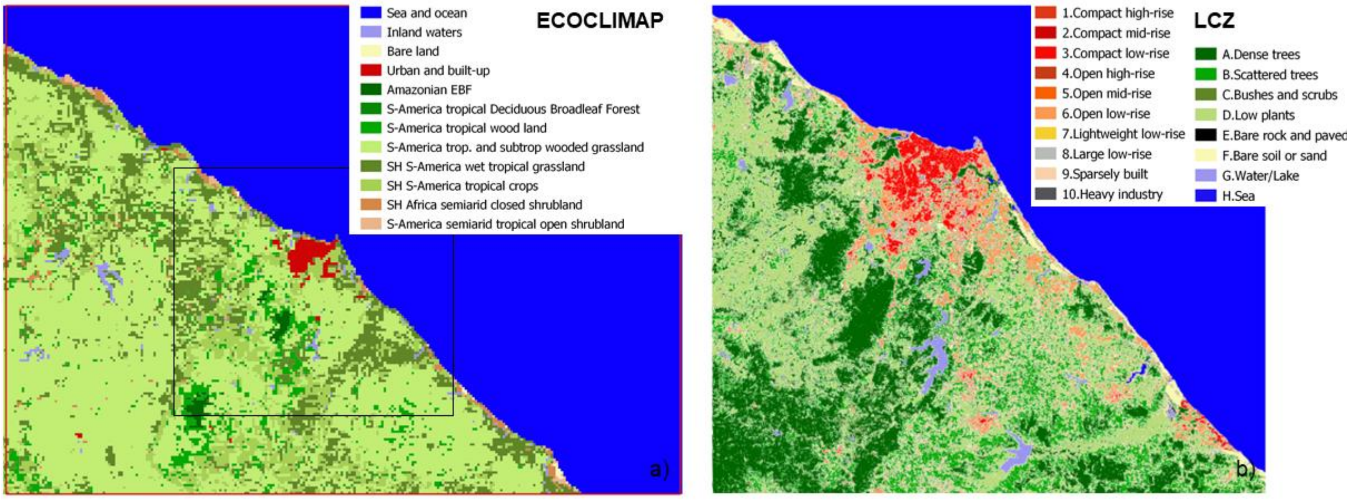

Figure 2 - a) HCLIM´s default global physiography database ECOCLIMAP-I at 1 km resolution (Masson et al., 2003) and b) the new LCZ map at 100 m resolution (© M. Demuzere, Ruhr University, Germany) to be placed on top of ECOCLIMAP (black line rectangle).

A five recent-past years (2009-2014) was selected based on in-situs observation data in comparison to the average parameter between 1966-2015 (JÚNIOR, 2018), in order to obtain a fully representativity of different typical climates in Fortaleza region (Table 1). For this period of 50 years, maximum, temperature (maximum, average and minimum) present a rising trend, while the relative humidity and precipitation tend to reduce. Observations indicate that the climate of 2012 is representative of the average trend. For this reason, 2012 is taken as the reference year for this study and to evaluate the performance the HCLIM system over Fortaleza and the with data available for 2012 are Castelão, Airport and UECE (Figure 3).

Table 1 - Climate representativity of the years between 2009 and 2014.

Climate	2009	2010	2011	2012	2013	2014
Normal				X		
Cold/Wet	X		X			
Cold/Dry						X
Warm/Dry		X			X	

The second period of simulation comprises the monitoring campaign of October 2019. Although this is a short period, a larger number of observation sites (14 low-cost sensors) is available (Figure 3). The sensors and weather stations sites are used to study different intra-urban thermal clusters and thus take conclusions on the relationship between climate/physiography and thermal comfort. To guarantee the reliability of the campaign data, it is also compared to the official weather stations available and to the model results.

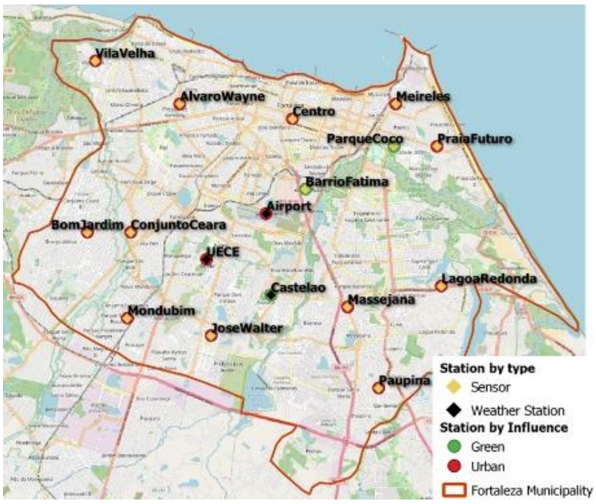

Figure 3 - Location of the meteorological sensors (monitoring campaign 2019) and fixed stations (2012).

4. PRELIMINARY RESULTS

4.1. HCLIM performance assessment

The year of 2012 (reference year) is used to assess performance of the modelling system and it is based on the Taylor diagram and 3 statistical parameters: the correlation factor (R), the systematic error (bias) and the root mean square error (RMSE).

Observations the weather stations (Figure 3) are compared to the model results to calculate the statistical parameters. The average values of the statistical parameters for those three sites concerning the all year of 2012 as well as the monthly R are depicted in Figure 4. In general, the statistical parameters suggest that HCLIM performs well within the interesting area of the simulation domain (Fortaleza city). Nevertheless, it is evident that the model performances better during the dry season (from July to December) for T2m and RH2m than during the rainy season. The weaker performance during the rainy season might be explained by the precipitation. The tropical rain events are intense events in Fortaleza that occur often for a short period. Therefore, it is more difficult for the model to predict them. Regarding the three observation sites, HCLIM presents a better performance in Castelão followed by UECE, having the weakest performance at the Airport site. From a pre-analysis of the monitored data in all the weather stations, Castelão was the one that presented less lacks of data and less inconsistent values.

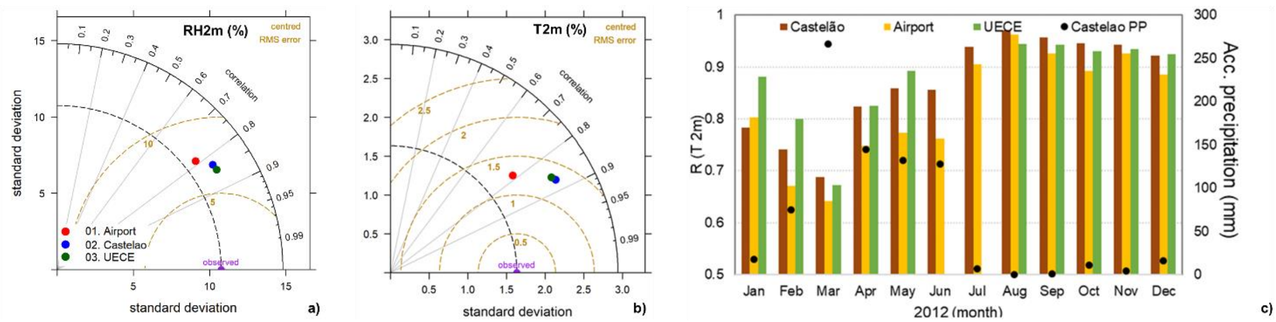

Figure 4 - HCLIM performance assessment for 2012. Taylor diagram for a) RH2m and b) T2m. c) Montly R for T2m and accumulated precipitation.

In October 2019, as part of the dry season, HCLIM presents a good performance. The mean statistical parameters for T2m and RH2m are: R_{T2m} = 0.93, $bias_{T2m}$ = -0.09°C) and $RMSE_{T2m}$ = 1.10°C); R_{RH2m} = 0.88, $bias_{RH2m}$ = -5.40% and $RMSE_{RH2m}$ = 8.01%.

4.2. Relationship between temperature and urban fraction

As depicted in Figure 5, the warmest areas in the city are those where urbanization is more intense (see also Figure 2b). In fact, either for 2010 and 2012, T2m and urban fraction present a correlation of >50%. It is also important to mention that the areas with higher temperatures match with the locations where the most socio-economic venerable populations live.

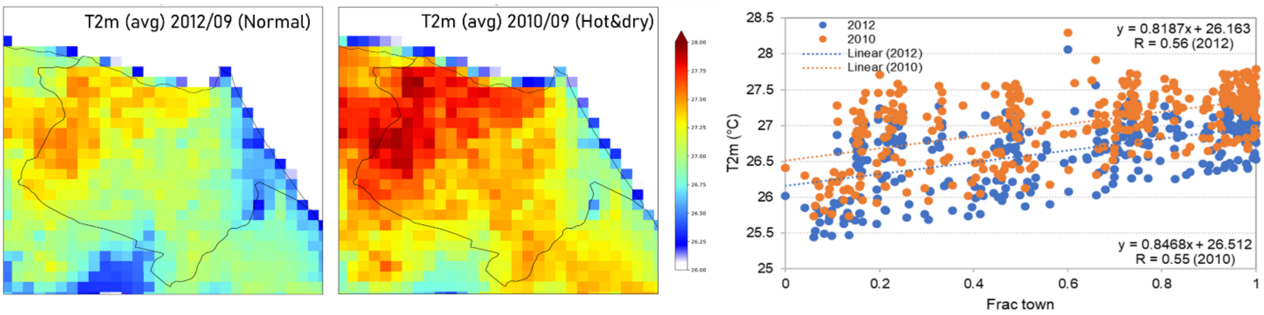

Figure 5 - Average of T2m during September 2012 (reference; left) and September 2010 (warm/dry; centre) and the relation between T2m and urban fraction for both periods (right).

4.3. Thermal Comfort

Thermal comfort wise, the Universal Thermal Comfort Index (UTCI, Figure 6) indicates that March (within the wet season) is less pleasant than September (within the dry season) in Fortaleza. This is mainly due to the higher humidity levels in the wet season in comparison to the dry season (ΔRH ≈20%). In fact, the temperature does not seem to have a significant role on the differences of UTCI levels along the year, because the annual temperature variation is small (max 2°C). The conjugation of temperatures around 25-30°C and high levels of humidity during the wet period, potentiate the evapotranspiration during the day from the sunrise (8:30 UTC) to zenith time (16:00 UTC) leading to a higher UTCI in natural (green and blue) areas than in urbanized areas.

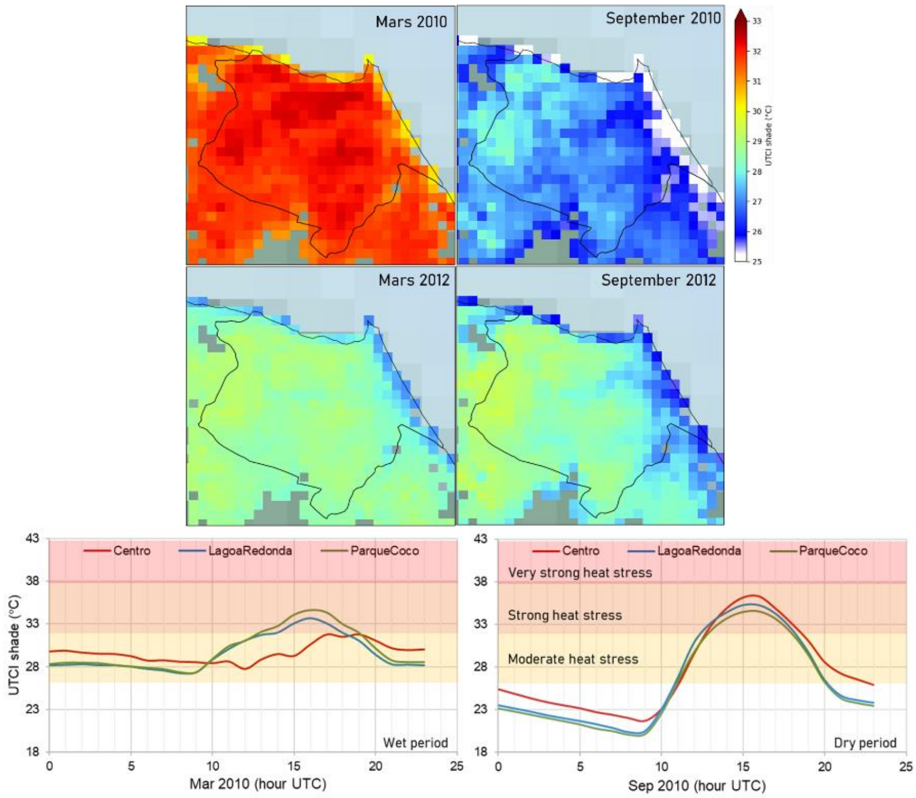

Figure 6 - Average UTCI in March (wet season) and September (dry season) of 2010 and 2012 (top). Daily profile of UTCI in March and September of 2010.

5. FINAL CONSIDERATIONS

- In Fortaleza, as a tropical-coastal city, precipitation is key to characterize the local climate.
- The most densely urbanized city areas are also those that present the highest thermal stress and where the most vulnerable population live.
- UTCI is higher during the wet season (Feb-Jun) than during the dry season, mainly due to the high levels of humidity.
- During the wet season UTCI varies between moderate at night to strong heat stress in day-light time at park and lake sites, while it keeps a moderate level in urban areas.

- Natural areas, like parks and lakes, presents the highest heat stress during the day in the wet season, while urban areas are more vulnerable to heat in the dry season.
- As conclusões devem ter uma relação direta com o objetivo do trabalho e com os resultados.
- A numeração começa na introdução e acaba nas conclusões.

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ACKNOWLEDGEMENTS

This study was performed under the scope of the bilateral cooperation project TropiCool, with funding from the Swedish Ministry of Environment and Energy and the Federal University of Ceará, Brazil. The authors would like to thank Matthias Demuzere (Ruhr University, Germany) for providing the LCZ map, Mário Filho and Meiry Sakamoto (Funceme, Fortaleza) for the meteorological data, and all the UFC students that participated in the campaign.