

Surface Temperature and NDVI Behavior Analysis in September in Manaus/AM City

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Abstract— The city of Manaus has been going through a process of accelerated and disorganized urban growth, which causes situations that characterize many challenges and environmental problems. Among these, we highlight the change in the local climate, causing the so-called Urban Heat Island (UHI) that arises in the area of the metropolitan region and is characterized by the rise in surface temperature when compared to the predominant temperature in the regions of urban sites. This phenomenon relates to anthropic activities on the surface and its consequence in the lower troposphere, which results in the increase in average temperatures and the number of hot days, intensifying thermal discomfort in the population. Thus, the objective of this work is to analyze the evolution of the heat island in the geographic space of the city of Manaus in the last 10 years, using remote sensing data, to estimate the values of surface terrestrial temperature, using Thermal maps generated from composites of AQUA satellite images, MODIS sensor: Surface Temperature and NDVI from THE LPDAAC (Land Processes Distributed Active Archive Center, NASA. Based on the data and analyses performed, it was possible to see an increase in temperature with a temporal variation in the years 2010 to 2019 as well as the expansion of warmer spaces, which invigorates the influence of UHI in the amazonense metropolis.

Keywords— Surface temperature, heat islands, thermal comfort.

I. INTRODUCTION

During recent decades, high demographic, territorial and industrial growth in cities, causing changes to natural and built environments. The city of Manaus reached the mark of 2,182,763 inhabitants in 2019, representing a population growth of 1.74%, compared to the previous year, when the city had the number of 2,145,444 inhabitants (IBGE, 2019). The disorderly growth of cities can lead to problematic effects on urban climate issues (WERNECK, 2018). In addition, some studies such as Santos (2010) and Saydelles (2005) showed that the loss of vegetation, and soil are directly related to the atmosphere, because, as the soil is exposed and without vegetation will suffer a higher incidence of solar radiation thus changing the components of the energy balance and consequently the surface temperature.

The process of urbanization of the city of Manaus happened quickly and absent from planning. Its accelerated development has caused the city's vegetate areas to be drastically reduced, which has led to changes in geographic space and thus causing changes in the surface temperature (ST) terrestrial and adjacent air, favoring thus the development of microclimatic phenomena such as the heat islands (HI). In addition to the removal of vegetation cover, HIs can be intensified by asphalt of the streets, use

of construction materials and verticalization processes thus becoming the cities even more vulnerable to heating and training of areas overheated in cities.

The creation of HIs is a perennial problem in the 21st century, caused by the intense process of urbanization and industrialization of cities (RIZWAN et al., 2008). One of the causative agents of HI is the change in the amount of solar energy that falls on the earth's surface through physical mechanisms, which leads to the change of certain meteorological elements, specifically surface temperature and air. study conducted by Matson et al., (1978) in July 1977 in the United States of America (USA), the authors showed the emergence of an amount greater than 50 urban heat islands, evidencing a temperature gradient of 2.6 °C to 6.5°C between urban and zone Rural.

Over the years the way in which urban space is used is altered by worsening the natural quality of the planet. Also, Neto and Amorim (2017) showed that temperatures are rising, in order to evolve the creation of heat islands, openly threatening the living conditions of fauna and flora, in addition to the quality of life of the population.

The phenomenon of UHI in the city of Manaus was addressed in Souza (2012) and Corrêa et. al., (2016), through the use of satellite images and information of

Numerical Models, the authors showed a significant increase in surface temperature in some regions of the city. Furthermore, HF is a phenomenon capable of causing great discomfort in the population, as it results in higher temperature indices and decreased air quality, causing greater possibilities of thermal stress, and may even cause diseases and serious damage in more sensitive individuals. In addition to bringing negative effects to the environment, as they contribute to the intensification of the effect of global warming and air pollution.

According to Assisi (2005), both temperate and tropical areas, UHI are related to local climate changes and the decrease in evaporative and convective cooling rates due to soil paving, reduction of vegetated areas, and also the reduction in wind speed due to increased surface roughness.

Thus, this work tried to show a temporal analysis of ST and vegetation index (NDVI) during the period from 2010 to 2019. Seeking to quantify variations in NDVI and ST and relate to urban expansion of the city of Manaus associated with thermal comfort, atmospheric phenomena such as El Nino South Oscillation and precipitation variations in this period.

II. MATERIAL AND METHODS

The city of Manaus/AM is located in the heart of the legal Amazon, around 3°S latitude and 60° W longitude, between the Negro and Amazonas rivers. Despite its location the city between the forest and the rivers, the city has shown strong population growth, which allows the rise of the islands of heat. Thus, data from the AQUA satellite, moderate resolution imaging spectroradiometer (MODIS): Surface Temperature (ST) and Normalized Difference Vegetation Index (NDVI) of the National Aeronautics and Space Administration (NASA) were used, through the LAND Processes Distributed Active Archive Center (LP) available in : <https://e4ftl01.cr.usgs.gov/MOLA/> and <https://e4ftl01.cr.usgs.gov/MOLT/>, validated in Wan (2008). The analysis was carried out in September during the ten-year period (2010 to 2019). The PRODUCT MYD11A2, provide Kelvin-grade TS with 1 km x 1 km pixel spatial resolution, and 4-hour time. In addition, the MOD13A3 product provides daily images of the vegetative index (NDVI), with spatial resolution of 1 km x km. The NDVI is the response of wavelength reflected by the vegetation of the earth's surface. Finally, the accumulated rainfall was used in September, from 2010 to 2019, obtained through the database of the National Institute of Meteorology.

The method used in this work was the qualitative analysis of the images, and through them to identify the

evolution of the heat islands. During the 10 years, the maximum/minimum TS was verified during the month of September, considered the hottest and drier month in the Amazon region. For this, an average of all images made available, pixel by pixel, the final product being the monthly image. Considering that the images are global, only the area that delimits the city of Manaus/AM was selected. The averages were also calculated in each pixel of surface reflectance; thus, it was possible to compare the maximum and minimum temperature areas with the areas of significant vegetation cover or not.

III. RESULTS AND DISCUSSIONS

Located near the Equator line (latitude and longitude), the city of Manaus/AM is located in a privileged geographical position, in the watershed, and the largest rainforest in the world. Despite this, in recent years, with the exponential growth of the population and consequently, urban areas grow. Thinking about it, through Figures 2 through 4 we will show the spatial distribution of TS and NDVI during september, from 2010 to 2019. While Figure 5 will show the accumulated rainfall in August and September of the years analyzed. In order to understand the signing of the development of HI in Manaus, Figure 1 presents the location of the areas and neighborhoods of the city.

Observing the average ST in September 2010 (Figure 2a) it is possible to identify a well-defined area with high ST, which can reach maximums around 47°C in the north, south center and midwest zones (represented in Figure 1 with dark green color, orange and white). It is worth mentioning that, analyzing Figure 2b, it is noted that these areas of Maximum ST coincide with the areas with the lowest emissivity of the vegetation. The areas of low emissivity represent places with absence or very little vegetation, constructions and waterproof areas. In addition, the months of September in the northern region is considered one of the hottest and driest months of the year which contribute to the increase in ST. When we analyze rainfall totals for the month of September (Figure 5) it is evident the low values accumulated around 26.6 mm, which contribute to the increase in ST. Together in September, accumulated rain in August is also shown to be low while maintaining the soil even drier, decreasing emissivity by vegetation (Figure 1b).

The year 2011 was marked by the decay of high temperatures (Figure 2c) in almost all areas of the city of Manaus, restricting high temperatures to a narrower range between the central south and midwest zones and a small core to the north. This decay is possibly associated with increased precipitation during the months of August and September with accumulated around 60 mm. It is

important to highlight that the year 2010/2011 was characterized as a year of La Nina (cold phase of the El Niño South Oscillation Phenomenon - ENSO) which explains the decrease in ST. The increase in precipitation

and decrease in ST show the areas of representative NDVI in the satellite image (Figure 2d).

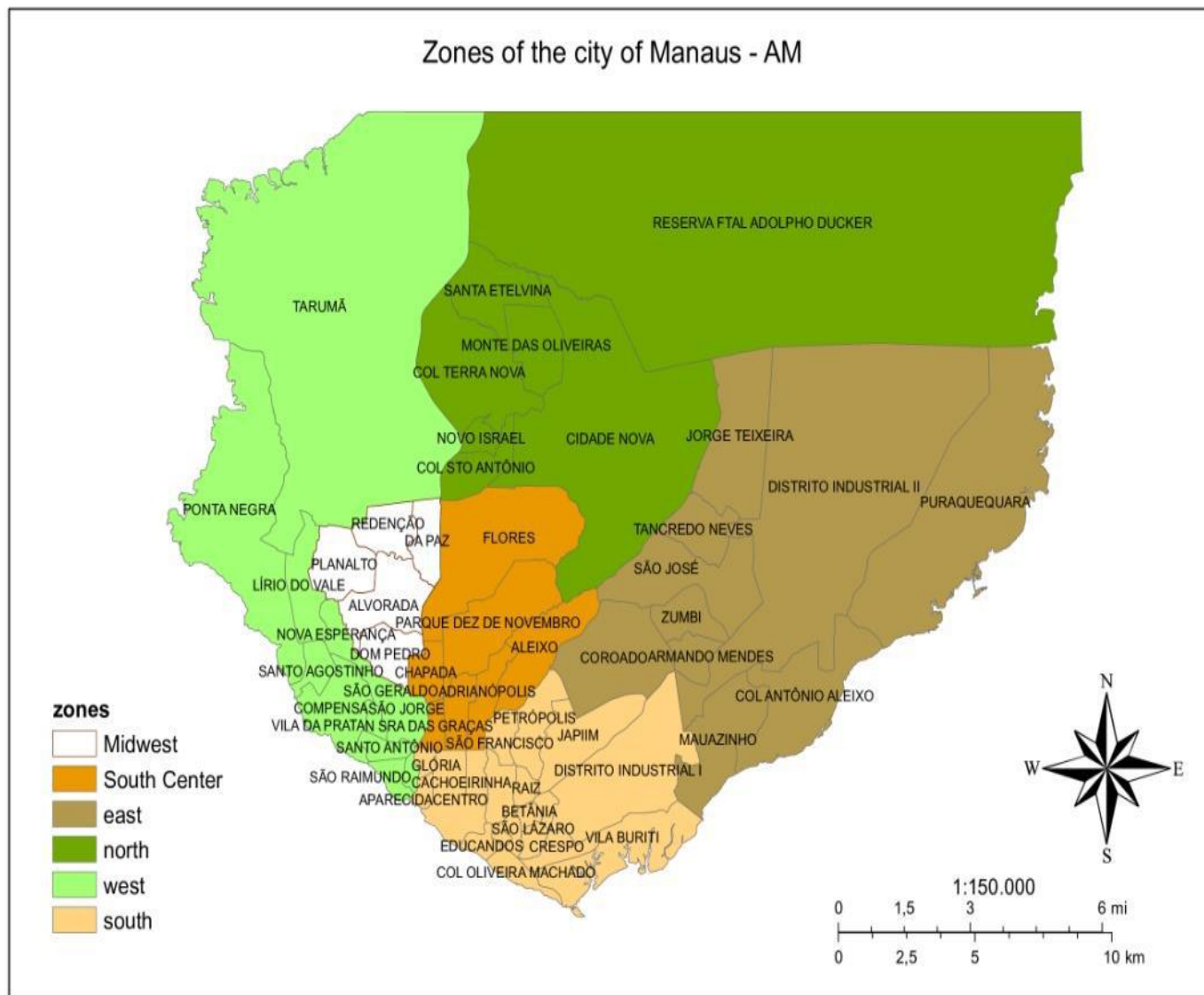


Fig.1: Location of areas and neighborhoods of the city of Manaus / AM

Presenting accumulated rainfall around 100 mm in September, 2013 is marked by the cooling of ST in virtually every city of Manaus (Figure 2f), showing only a small core with temperatures close to 47°C between the north and east zones. At the same time, this temperature decay is associated with accumulated rain in the month of

121 mm, which is above the climatological average. Evidence of this precipitation above expected for the month of September can also be verified in Figure 1g by the low values of surface emissivity which can characterize in a very humid soil, on the periphery of the map.

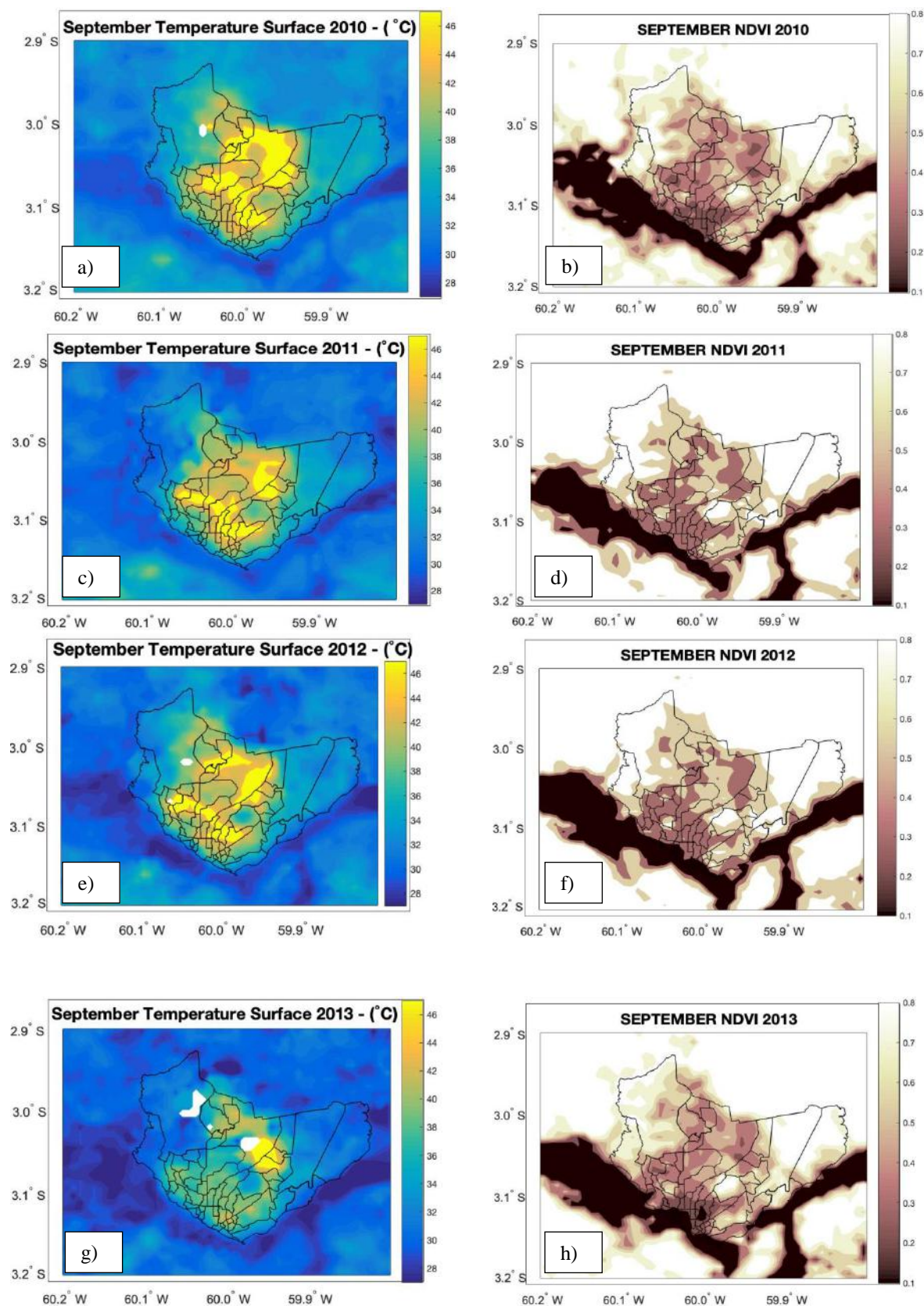


Fig.2: a) Surface temperature in September 2010;b) NDVIin September 2010;c) Surface temperature in September 2011; d) NDVIin September 2011;e) Surface temperature in September 2012;f)NDVI in September 2012; g) Surface temperature in September 2012;h)NDVI in September 2012.By satellite by MODIS satellite, 1x1km.

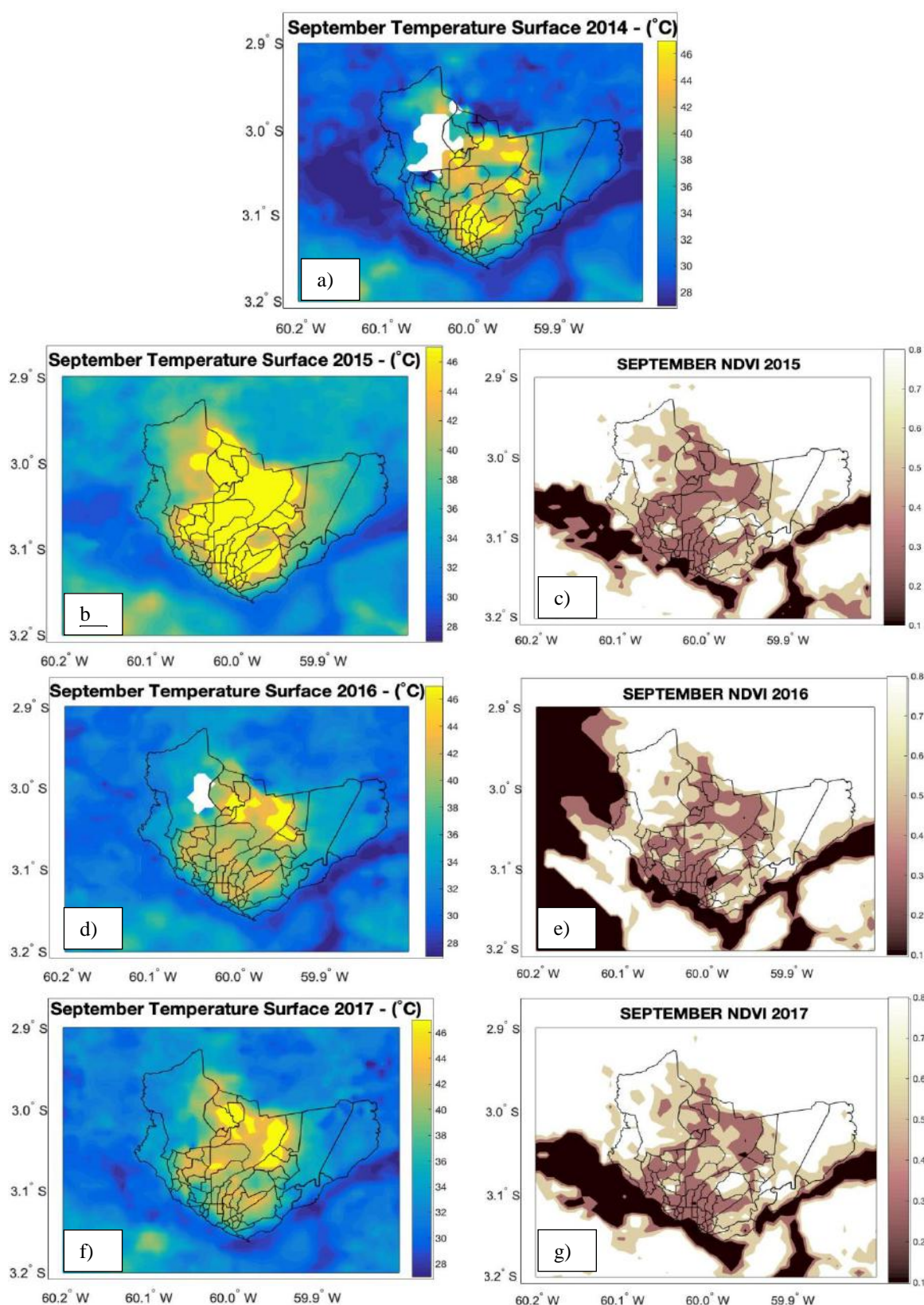


Figure 3: a) Surface temperature in September 2014; b) Surface temperature in September 2015; c) NDVI in September 2015; d) Surface temperature in September 2016; e) NDVI in September 2016; f) Surface temperature in September 2017; g) NDVI in September 2017. By satellite by MODIS satellite, 1x1km.

The year 2014 was marked by the increase of ST's throughout the metropolitan region of Manaus, mainly in the south and north regions, reaching highs of 46°C (Figure 3a). Due to technical issues, unable to create NDVI image.

The year 2015 is marked by an episode of ENOS in the hot phase, called El Niño. This phenomenon is characterized in the northern region by a period of prolonged extreme droughts, which further increases the foci of fires in the region. A set of factors such as low rainfall indices during August and September (Figure 5), weak emissivity emitted by the surface and El Niño-Southern Oscillation(ENSO) contributed to the increase in ST thus expanding HI. These expansions of areas with temperatures close to 47°C reached regions of the city that previously did not have such high Values of ST. Figure 3b shows that even the vast green area of the campus of the Federal University of Amazonas (UFAM) which is one of the most significant green areas of the city, presented more less ST values.

In other cases, the years 2016 and 2017 were marked by an increase in precipitation totals (above 100 mm) and consequently a decay of ST. These two years present a similar behavior of the spatiality of ST, in

addition to the similarity of NDVI maps. ST maximums are found in the north and east regions (Figure 3).

The last two years analyzed (2018/2019) were marked by a progressive increase in CI (Figure 4a and 4c), showing a predominance of the north and south-central regions. It is still possible to verify that although the north zone has high temperatures during all the years analyzed, in this region is located the Botanical Garden of the city. This fact shows us that despite the presence of extremely abundant vegetation is not enough to mitigate the effects of heat islands in the region.

Over the years the exponential growth of the city Manaus and consequently the decrease of its vegetated area in the urban environment, has transformed the climatic dynamics of the region. Knowing then that land use is of great importance, as its disorderly occupation causes the deterioration of the environment, the practices of management of the city's territory and its forms of land use robust with thermal variability and lime islands or. It is possible to observe a gradual growth of temperature with the flow of the years precipitously in the less vegetated regions and with higher rates of urbanization and verticalization.

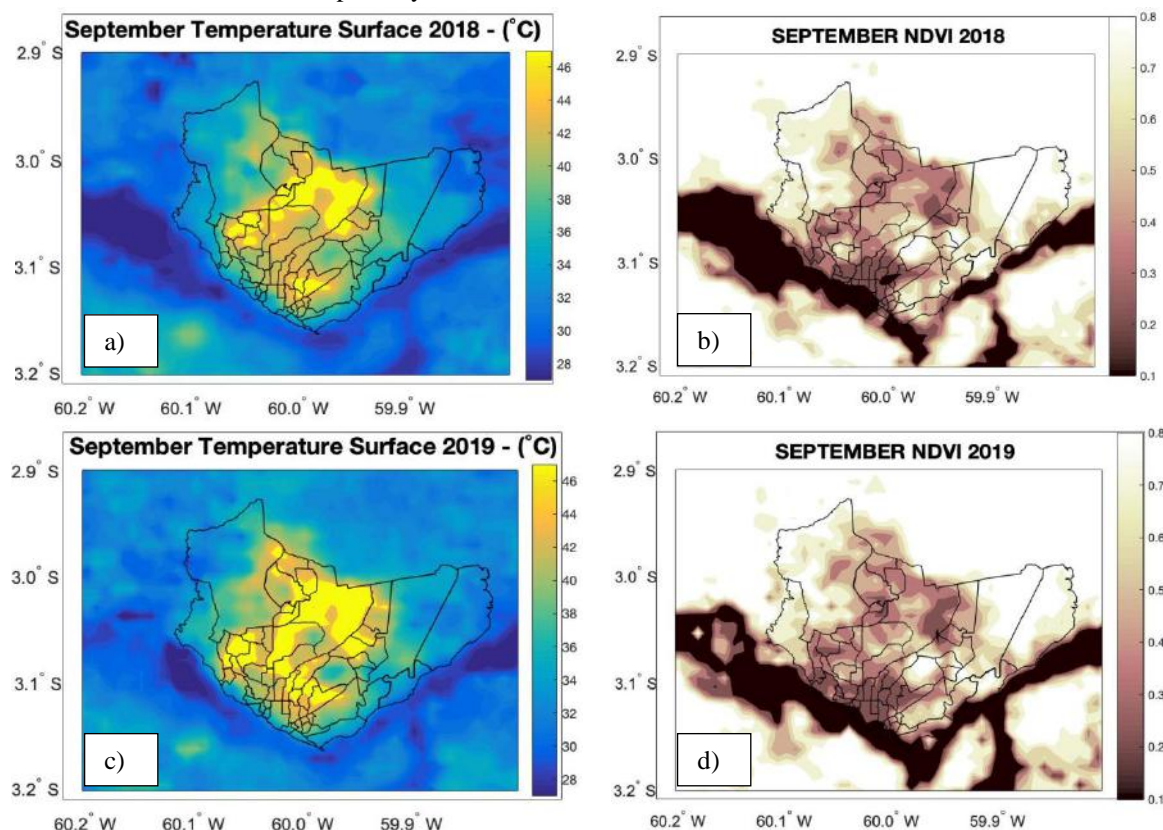


Fig.4: a) Surface temperature (°C) in September 2018; b) NDVI in September 2018; c) Surface temperature (°C) in September 2019; d) NDVI in September 2019; By satellite by MODIS satellite, 1x1km.

Regions with higher vegetation indexes record the lowest temperatures compared to the others, understanding that vegetation collaborates to mitigate the phenomenon of urban heat islands, contributing to the air being less hot. It

can be noted that the appearance of the most intense heat islands is most commonly in urban extension regions, as well as high temperatures.

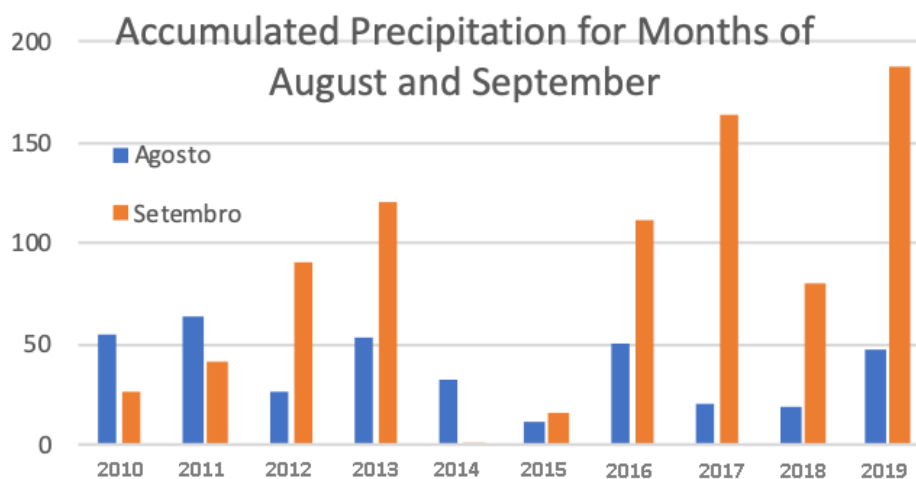


Fig.5: Accumulated precipitation (mm) in August (blue color) and September (orange color).

Figure 5 shows the degree of precipitation from 2010 to 2019 in August and September, which are the months of dry climate in the region. Manaus receives about 2,300 mm of rain per year, with its highest rainfall in december to May and decreases between June and November. In 2010 he heard a period of drought that is related to the occurrence of large-scale ocean-atmosphere coupled systems El Niño-Southern Oscillation (ENSO), which influenced the rainfall levels of the Amazon this year, leaving the rains less intense.

IV. FINAL CONSIDERATION

The city of Manaus/AM is known worldwide for its location next to the Amazon rainforest. Although tropical regions are characterized by high temperatures throughout the year, the forest has the role to collaborate in thermal comfort. On the other hand, the increase in urbanization, of spaces often built without any kind of inspection, are making the city of Manaus hotter every day. This work showed through MODIS images, that in the period 2010 to 2019 surface temperatures showed a significant increase, reaching values close to 47° C. These temperatures are concentrated in the "T zone" comprising the north, south and midwest areas. In parallel, in the same regions designated as "Zone T", NDVI images also showed a predominance of low emissivity, in all years, thus showing that the increase in temperature in these regions are characterized by vegetation.

REFERENCES

- [1] AGÊNCIA DE NOTÍCIA IBGE. IBGE divulga as estimativas da população dos municípios para 2019. 28 de agosto de 2019. Consultado em 20 de outubro de 2019.
- [2] ASSIS, E. S. de. A abordagem do clima urbano e aplicações no planejamento da cidade: reflexões sobre uma trajetória. In: ENCONTRO NACIONAL E IV ENCONTRO LATINO-AMERICANO SOBRE CONFORTO NO AMBIENTE CONSTRUÍDO, 8, 2005, Maceió. Anais. Maceió: ANTAC, 2005.
- [3] BRASIL. Lei Federal nº 10.257. Brasília, DF: Presidência da República, [2019]. Disponível em: http://www.planalto.gov.br/ccivil_03/LEIS/LEIS_2001/L10257.htm. Acesso em: 1 nov. 2019.
- [4] CORRÊA, P. B., CANDIDO, L. A., SOUZA, R. A. F. D., ANDREOLI, R. V., & KAYANO, M. T. (2016). Estudo do Fenômeno da Ilha de Calor na Cidade de Manaus/AM: Um Estudo a Partir de Modelagem e Estações Meteorológicas. *Revista Brasileira de Meteorologia*, 31(2), 167–176.
- [5] MATSON, M. E.; MCCLAIN, P. D.; MCGINNIS JÚNIOR, F.; PRITCHARD, J. A. Satellite Detection of Urban Heat Islands. NOAA/National Environmental Satellite Service, WashingtonDC, 20233, 1978.
- [6] NETO, A. T. N.; AMORIM, M. C. de C. T. Ilha de Calor Urbana e Desconforto Térmico: Uma Análise Episódica em Cuiabá/MT. I Congresso Nacional de Geografia Física. Os desafios da geografia física na fronteira do conhecimento. Instituto de Geociências –Unicamp, Campinas – SP, jun.–jul. 2017.
- [7] RIZWAN, A. M., DENNIS, Y.C., LEUNG, L. C., *et al.*, 2008, "A Review on the Generation, Determination and Mitigation of Urban Heat Island", *Journal of Environmental Sciences*, vol. 20.

- [8] SANTANA, R. A. S. de. Estudo do Escoamento Turbulento Atmosférico em Diferentes Sítios Experimentais Localizados na Amazônia. Universidade do Estado do Amazonas (UEA) - Instituto Nacional de Pesquisa da Amazônia (INPA) - Programa de Pós-Graduação em Clima e Ambiente – Cliamb. Tese. Manaus/AM - 2017.
- [9] SANTOS, E. M. dos. Estudo da Variabilidade e Mudanças Climáticas na Região de Manaus. Universidade do Estado do Amazonas (UEA) - Instituto Nacional de Pesquisa da Amazônia (INPA) - Programa de Pós-graduação em Clima e Ambiente – Cliamb. Dissertação (Mestrado). 2010. Manaus-AM.
- [10] SAYDELLES, A. P. Estudo do Campo Térmico e das Ilhas de Calor Urbano em Santa Maria-RS. Programação de Pós-Graduação em Geografia e Geociências (PPGGEO). Dissertação de Mestrado. Santa Maria-RS, 2005.
- [11] SOUZA, D. O. (2012). Influência da Ilha de Calor Urbana das Cidades de Manaus e Belém sobre o Microclima Local.
- [12] WERNECK, D. R. Estratégias de Mitigação das Ilhas de Calor Urbanas: Estudo de Caso em Áreas Comerciais em Brasília–DF. Dissertação de Mestrado. UNB –Universidade de Brasília. 2018.