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Heat Islands in México City: A Perspective from Remote Sensing Satellite Images

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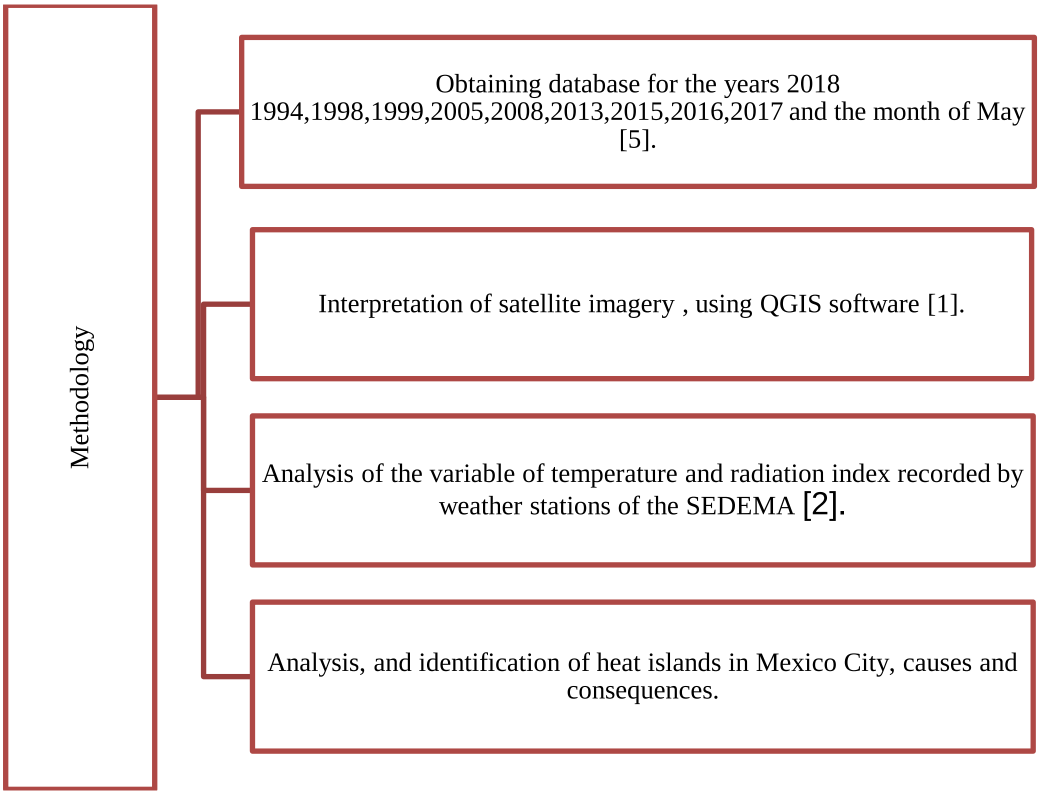
Abstract: It is known that heat islands today are very common in cities around the world, but how do you know if your city is affected by this phenomenon ? Mexican researchers have investigated for a long time on this phenomenon by obtaining more accurate results every time on the existence of heat islands, but ¿How is it that behaves in Mexico City? To give a solution to this questioning it was decided to carry out the following work which shows the presence of heat islands in Mexico City, causes and consequences in addition demonstrates the effect pan and its possible relationship with the development of severe storms all this from a perspective of satellite remote sensing.

Keywords: effect casserole, heat islands, México City, remote sensing, satellite

The heat island concept is defined as a phenomenon of thermal origin that occurs in urban areas, which consists of the variation of the temperature, which tends to be higher and contrasting. Experts, researchers attribute the development of this phenomenon to the air conditioning systems, cars, city lights, urban centers, construction materials, among others. This phenomenon is present in many cities where the growth of the city is exponential in nature, for example, New York, London, Mexico City (CDMX) to name a few. Putting us in the City of Mexico, various studies have been carried out in order to verify the existence of heat islands in the city, research institutes such as the Institute of Ecology of the UNAM [8], analyze meteorological variables, environmental impact in recent years and growth of the city in order to find a possible relationship for the formation of heat islands. Although the concept is not yet well defined for the city efforts to verify its existence have yielded to identify areas that are affected by this phenomenon. With the aim of contributing with the studies for the identification of heat islands in the City of Mexico and give sustenance to what has already been obtained from analysis of workstations, growth of the city and environmental impact is implemented the use of new technologies, technologies such as remote sensing imagery, which provides us with a wealth of tools achieving an even sharper vision of what today we can find when using instrumentation on earth. This paper used remote sensing imagery from Landsat 5,7 and 8 [5], satellites of American origin of the U.S. Geological Survey (USGS), images that were subsequently processed in the QGIS software (version 2.18.23 "Las Palmas") getting valuable information that contributes to the study and identification of heat islands in Mexico City (CDMX).

METHODOLOGY



Methodology implemented to carry out the analysis, interpretation and identification of heat islands in Mexico City [1].

Table 1: Equations and parameters for the analysis of satellite images [1].

Equation	Parameter
1. $L\lambda = M_L * Q_{cal} + A_L$ Spectral radiance	$M_L = RADIANCE\_MULT\_BAND\_X$ $A_L = RADIANCE\_ADD\_BAND\_X$ $M_L =$ Previously translated to ND Band
2. $\rho_\lambda = \frac{M_p * Q_{cal} + A_p}{\sin\theta_{se}}$ With angular reflectance correction	$M_p = REFLECTANCE\_MULT\_BAND\_X$ $A_P = REFLECTANCE\_ADD\_BAND\_X$ $Q_{cal} =$ Previously translated to ND Band $\theta_{se} = SUN\_ELEVATION$
3. $T = \left[\frac{\left(\frac{k_2[TIRS\ 1]}{\ln\frac{K1[TIRS\ 1]}{L_\lambda[TIRS\ 1]}+1}\right)+\left(\frac{k_2[TIRS\ 2]}{\ln\frac{K1[TIRS\ 2]}{L_\lambda[TIRS\ 2]}+1}\right)}{2}\right]$-273,15 Brightness Temperature	$k_1 = K1\_CONSTANT\_BAND\_X$ $k_2 = K2\_CONSTANT\_BAND\_X$ $L_\lambda =$ Previously translated to Radiance Band
4. $NDVI = \frac{\left[\left(\frac{I\text{Near Infrared} - Red}{I\text{Near Infrared} + Red}+1\right)*10\right]}{2}$ Standardized Indices of Vegetation Index (NDVI)	$Near\ Infrared$ = Previously translated band reflectance $Red =$ Previously translated band reflectance
5. $MNDWI = \frac{\left[\left(\frac{\text{green} - \text{Medium Infrared}}{\text{green} + \text{Medium Infrared}}+1\right)*10\right]}{2}$	$Green =$ Previously translated band reflectance $Medium\ infrared$ = Previously translated band reflectance

Modification of Standardized Indices of Water (MNDWI)	
6.- $\text{VegetationHealth} = \frac{\left[\left(\frac{M_p * Q_{cal} + A_p}{\sin\theta_{se}} + 1\right) * 10\right]}{2}$ Vegetation Health	$M_p = REFLECTANCE\_MULT\_BAND\_X$ $A_P = REFLECTANCE\_ADD\_BAND\_X$ Q_{cal} = Previously translated to ND Band $\theta_{se} = SUN\_ELEVATION$

AREA OF STUDY

Identification of the area of study where we can observe the delimitation of the code obtained from a file shape of Mexico. On the observed distribution of the urban area until the year 2017 processed with data from INEGI [6].

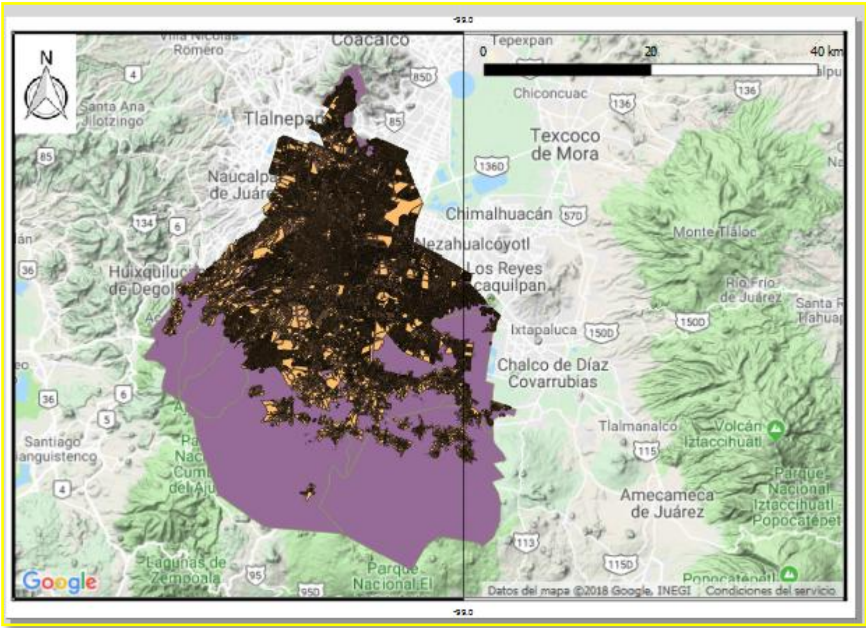


Figure 1: Location of Mexico City, distribution of urban sprawl with data from INEGI [6].

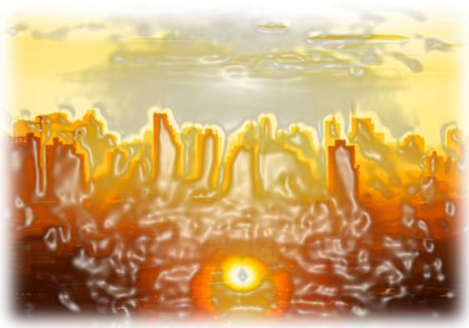
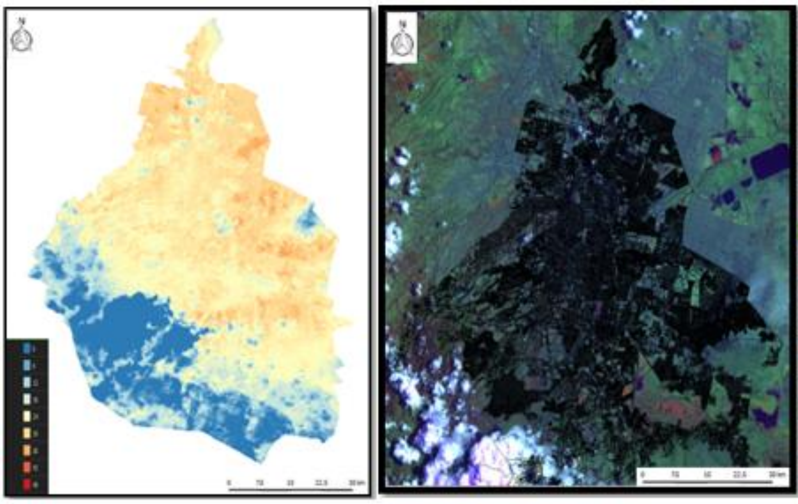


Figure 2: Heat islands in Mexico City (Source: http://www.unamglobal.unam.mx)

RESULT

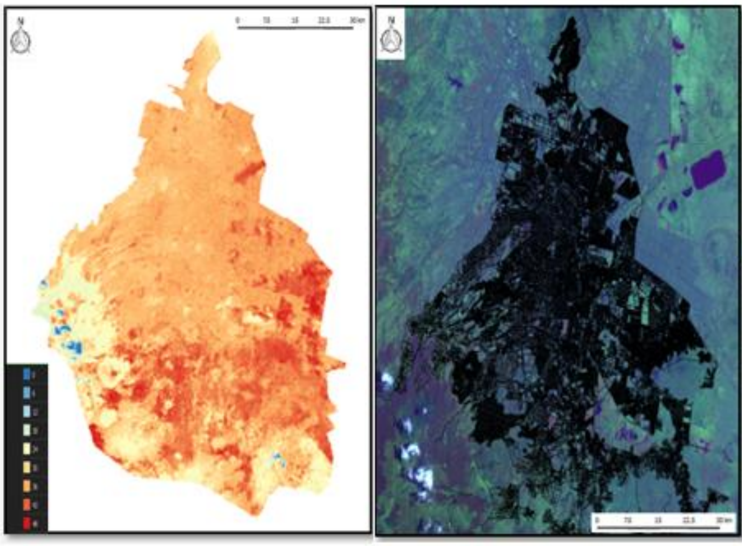
To display a general analysis to carry out the processing of Landsat satellite images [5], we find the behavior of plant health (Equation 1,2 and 6) that surrounds the City of Mexico with the purpose of observing how this is compounded over the year product in the presence of heat islands. To do this it was necessary to carry out a virtual combination (equation 1,2,4 and 6) and observe the behavior of the surrounding vegetation to Mexico City.



FECHA	HORA	TAC	FAC	TLA	MER
16_may_94	1	14.5	14	14.1	15.7
16_may_94	2	13.7	13.3	13.3	14.8
16_may_94	3	13.2	13.2	12.7	14.1
16_may_94	4	13.4	13.5	12.7	14
16_may_94	5	12.9	12.9	12.5	13.6
16_may_94	6	12	11.7	12.3	13.3
16_may_94	7	11.7	11.3	12.2	13.5
16_may_94	8	13.8	13.8	13.6	14.4
16_may_94	9	16.4	16.5	16.7	16.5
16_may_94	10	18.6	18.3	19.8	18.5
16_may_94	11	20.2	20	22.3	20.1
16_may_94	12	22.1	22.3	22.9	22.5
16_may_94	13	22.9	22.7	23.7	24.5
16_may_94	14	22.3	21.8	23.9	24.8
16_may_94	15	23	22.5	24.3	23.7
16_may_94	16	22	20.5	21.5	23.9
16_may_94	17	17.2	16.9	19.5	20.1
16_may_94	18	19.4	18.9	20.1	20.6
16_may_94	19	19.3	18.7	19.4	20.2
16_may_94	20	18.6	18	18.6	19.1
16_may_94	21	17.8	16.7	17.8	17.9
16_may_94	22	15.7	14.9	15.2	17.3
16_may_94	23	14.7	14.3	14.4	16.1
16_may_94	24	14.2	14.1	14.4	16

Figure 3: Temperature Distribution (Equation 1,2 and 3), virtual combination vegetation (1,2,4 and 6) equation and temperatures obtained from meteorological stations of the SEDEMA for 16 May 1994 [2].

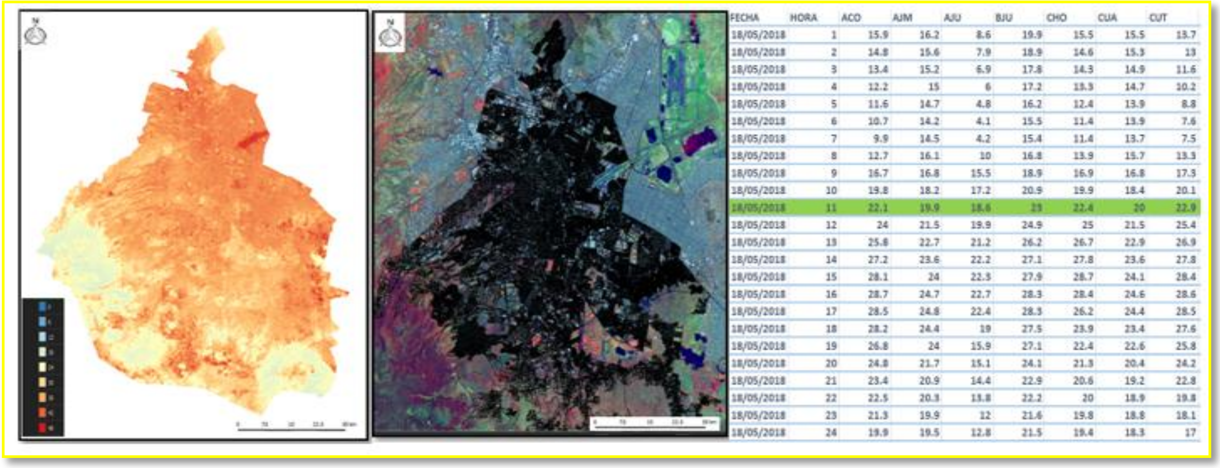
It can be seen that the health of vegetation in the metropolitan area to Mexico City shown well, while more shop to the dark green will show greater health however while more shop to red will show considerable damage. In the case of the analysis of the temperature distribution show values on the order of 24 - 36 °C, unlike the weather stations which show values on the order of 20 - 22°C.



FECHA	HORA	FAC	SAG	XAL	MER	PED
11_may_9	1	19.2	19.9	21.5	21.4	20
11_may_9	2	17.7	19.2	20.6	20.6	18.7
11_may_9	3	17	19.2	19.6	19.9	18.1
11_may_9	4	16.6	17.5	19.1	19.3	17.4
11_may_9	5	15.7	17.4	18.7	18.3	16.7
11_may_9	6	14.6	16.4	18	17.6	16.5
11_may_9	7	14.1	15.1	17.7	17.4	16.4
11_may_9	8	16.5	15.2	17.9	18.4	17.7
11_may_9	9	20.8	18.3	20.1	20.8	20.3
11_may_9	10	23.5	22.3	23.8	23.6	23.5
11_may_9	11	25.5	25.6	26.4	26.5	25.8
11_may_9	12	28.1	28.7	29.6	29.3	28.1
11_may_9	13	30.4	29.7	31.5	31.9	29.9
11_may_9	14	31.8	30.9	31.5	33	31.1
11_may_9	15	31.5	31.8	32.4	32.7	30.1
11_may_9	16	29.6	32	32.8	31.3	26.7
11_may_9	17	24.9	29.2	29	28.6	24.4
11_may_9	18	24.5	27.2	27.1	27.1	23.6
11_may_9	19	22.9	26	26.4	26.6	23.1
11_may_9	20	23.1	24.9	25.6	25.9	22.2
11_may_9	21	21.9	22.8	23.6	23.7	21.2
11_may_9	22	21.5	22.2	23	21.8	20
11_may_9	23	19.6	22.1	22.3	21.5	19
11_may_9	24	19.6	21.9	21.8	21.1	18.7

Figure 4: Temperature Distribution (Equation 1,2 and 3), virtual combination vegetation (1,2,4 and 6) equation and temperatures obtained from meteorological stations of the SEDEMA for 11 May 1998 [2].

For the 11 May 1998 we can see that the health of vegetation in the metropolitan area to Mexico City begins to show signs of deterioration, while more shop to the dark green will show greater health however while more shop to red will show considerable damage. In the case of the analysis of the temperature distribution show values on the order of 24 - 47 °C, unlike the weather stations which show values on the order of 25 - 27°C.



FECHA	HORA	ACO	AJM	AJU	BJU	CHO	CUA	CUT
18/05/2018	1	15.9	16.2	8.6	19.9	15.5	15.5	13.7
18/05/2018	2	14.8	15.6	7.9	18.9	14.6	15.3	13
18/05/2018	3	13.4	15.2	6.9	17.8	14.3	14.9	11.6
18/05/2018	4	12.2	15	6	17.2	13.3	14.7	10.2
18/05/2018	5	11.6	14.7	4.8	16.2	12.4	13.9	8.8
18/05/2018	6	10.7	14.2	4.1	15.5	11.4	13.9	7.6
18/05/2018	7	9.9	14.5	4.2	15.4	11.4	13.7	7.5
18/05/2018	8	12.7	16.1	10	16.8	13.9	15.7	13.3
18/05/2018	9	16.7	16.8	15.5	18.9	16.9	16.8	17.3
18/05/2018	10	19.8	18.2	17.2	20.9	19.9	18.4	20.1
18/05/2018	11	22.1	19.9	18.6	23	22.4	20	22.9
18/05/2018	12	24	21.5	19.9	24.9	25	21.5	25.4
18/05/2018	13	25.8	22.7	21.2	26.2	26.7	22.9	26.9
18/05/2018	14	27.2	23.6	22.2	27.1	27.8	23.6	27.8
18/05/2018	15	28.1	24	22.3	27.9	28.7	24.1	28.4
18/05/2018	16	28.7	24.7	22.7	28.3	28.4	24.6	28.6
18/05/2018	17	28.5	24.8	22.4	28.3	26.2	24.4	28.5
18/05/2018	18	28.2	24.4	19	27.5	23.9	23.4	27.6
18/05/2018	19	26.8	24	15.9	27.1	22.4	22.6	25.8
18/05/2018	20	24.8	21.7	15.1	24.1	21.3	20.4	24.2
18/05/2018	21	23.4	20.9	14.4	22.9	20.6	19.2	22.8
18/05/2018	22	22.5	20.3	13.8	22.2	20	18.9	19.8
18/05/2018	23	21.3	19.9	12	21.6	19.8	18.8	18.1
18/05/2018	24	19.9	19.5	12.8	21.5	19.4	18.3	17

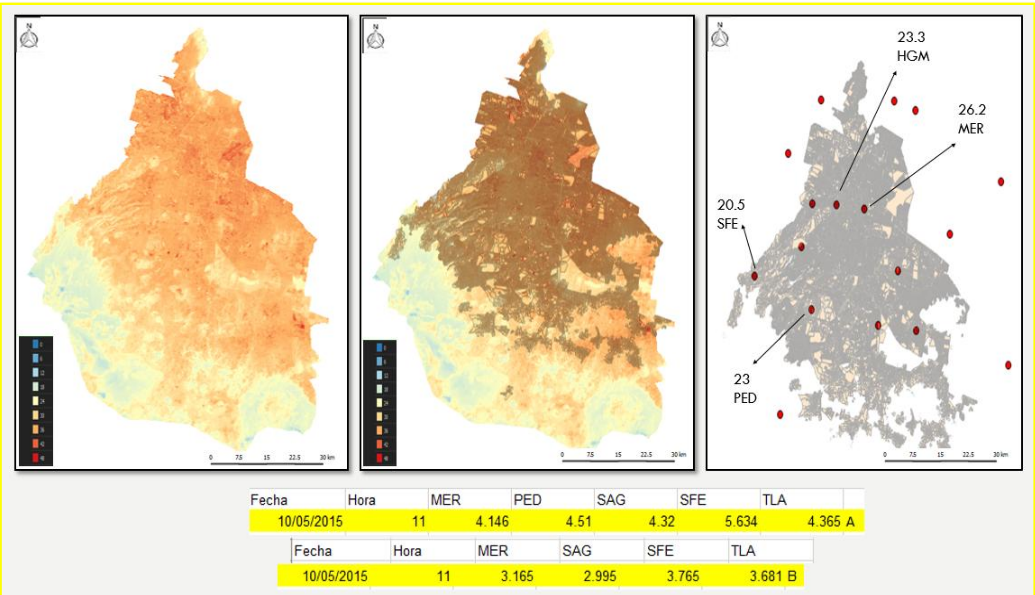
Figure 5: Temperature Distribution (Equation 1,2 and 3), virtual combination vegetation (1,2,4 and 6) equation and temperatures obtained from meteorological stations of the SEDEMA for 18 May 2018 [2].

Doing the same process for each of the years we can see that the vegetation is undergoing changes where their signs of healthy vegetation decrease due to the presence of heat islands. For the 18 May 2018 which for Mexico City was considered as one of the years with higher rates of UV radiation we can see that the health of vegetation in the metropolitan area to Mexico City shows signs of deterioration, while more shop to the dark green will show greater health however while more shop to red will show considerable damage. In the case of the analysis of the temperature distribution show values on the order of 24 - 45 °C, unlike the weather stations which show values on the order of 18 - 23°C.

Up to this time observed that 9 May 1998 was the warmest day for Mexico City while maintaining the historic so far on the basis of the comparison of data from meteorological stations however the maps obtained from Landsat satellite images [5] show that thermal bands detected temperatures are above that of the seasons which leads us to think about the presence of heat islands.

DETERMINATION OF HEAT ISLANDS IN MEXICO CITY

For the determination of heat islands the next comparison between meteorological stations of the SEDEMA, indices of radiation provided by stations of the SEDEMA [2] and the satellite images provided by the Landsat 8 [5].



Fecha	Hora	MER	PED	SAG	SFE	TLA
10/05/2015	11	4.146	4.51	4.32	5.634	4.365 A

Fecha	Hora	MER	SAG	SFE	TLA
10/05/2015	11	3.165	2.995	3.765	3.681 B

Figure 6: Analysis of temperature distribution with data obtained from Landsat 8 [5], the distribution of urban sprawl with data from INEGI [6], analysis of meteorological variables of radiation and temperature SEDEMA [2] for the determination of heat islands of 10 May 2015.

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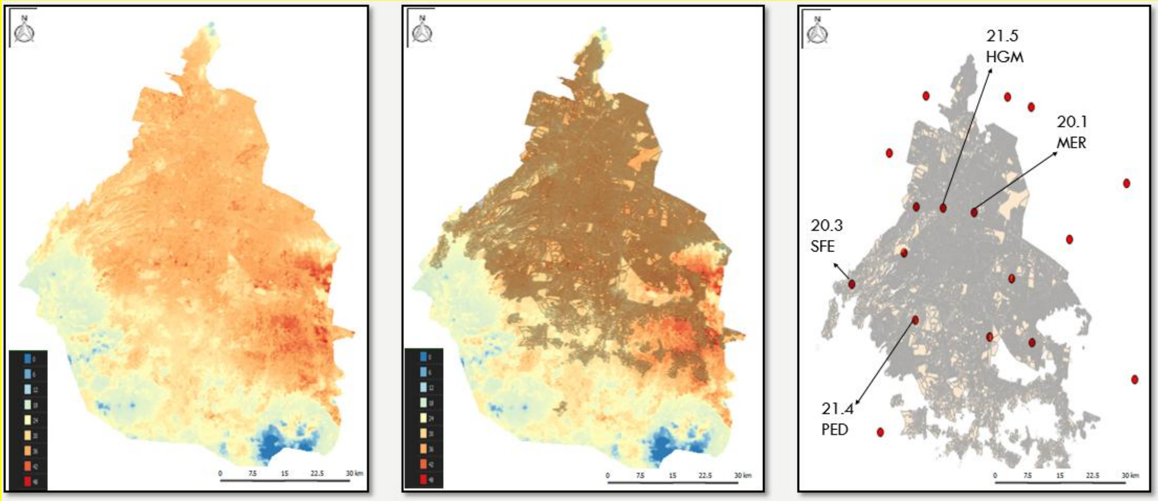
The results obtained for May 2015 show that the temperature data of meteorological stations, the rates of short wave UV radiation (A, B) long wave of meteorological stations [2] and the distribution of temperature obtained by Landsat 8 [5], do not show a relationship. The satellite image shows the concentration of temperature in the center, north and east of the city which corresponds with the largest concentration of distribution of urban sprawl, concluding with the presence of heat islands in Mexico City for this year.

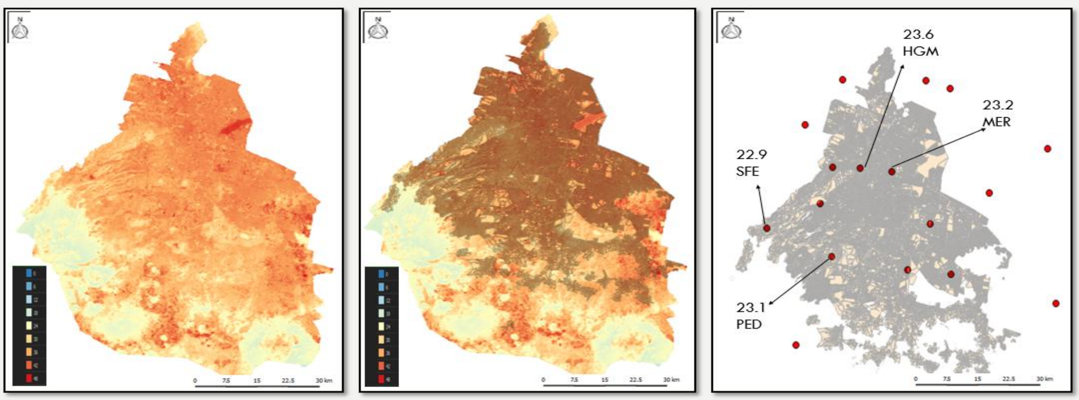


Fecha	Hora	FAC	MER	MON	PED	SAG	SFE
28/05/2016	11	3.542	3.022	3.529	3.8	2.838	3.539 B

Fecha	Hora	CHO	CUT	FAC	MER	MON	PED	SAG	SFE
28/05/2016	11	4.101	4.505	4.294	3.903	4.354	5.439	4.293	5.467 A

Figure 7: Analysis of temperature distribution with data obtained from Landsat 8 [5], the distribution of urban sprawl with data from INEGI [6], analysis of meteorological variables of radiation and temperature SEDEMA [2] for the determination of heat islands of 28 May 2016.

For the analysis of the month of May 2016 shows that the temperature data of meteorological stations, the rates of short wave UV radiation (A, B) long wave of meteorological stations [2] and the distribution of temperature obtained by Landsat 8 [5], do not show any relationship between them. The satellite image shows the concentration of temperature in the center, north and east of the city which corresponds with the largest concentration of distribution of urban sprawl, concluding with the presence of heat islands in Mexico City for this year.



Fecha	Hora	CHO	LAA	MER	MON	SAG
18/05/2018	11	3.482	2.98	3.381	3.709	3.323 B

Fecha	Hora	CHO	LAA	MER	MON	SAG
18/05/2018	11	4.505	4.376	4.129	4.711	4.39 A

Figure 8: Analysis of temperature distribution with data obtained from Landsat 8 [5], the distribution of urban sprawl with data from INEGI [6], analysis of meteorological variables of radiation and temperature SEDEMA [2] for the determination of heat islands of 18 May 2018.

Finally, for the analysis of the month of May 2018 shows that the temperature data of meteorological stations, the rates of short wave UV radiation (A, B) long wave of meteorological stations [2] and the distribution of temperature obtained by Landsat 8 [5], do not show any relationship. The satellite image shows the concentration of temperature in the center and north of the city center, which corresponds with the largest concentration of distribution of urban sprawl, concluding with the presence of heat islands in Mexico City.

By performing this analysis for each of the years proposed, it is concluded that the heat islands there are in Mexico City and these are dynamic as they move from one place to another in short periods of time. This is where the question arises what consequences have heat islands and how it is affecting the city of Mexico? In response to this, an analysis is carried out to micro scale with the purpose of giving an answer and demonstrate that Mexico City is affected by the effect Casserole.

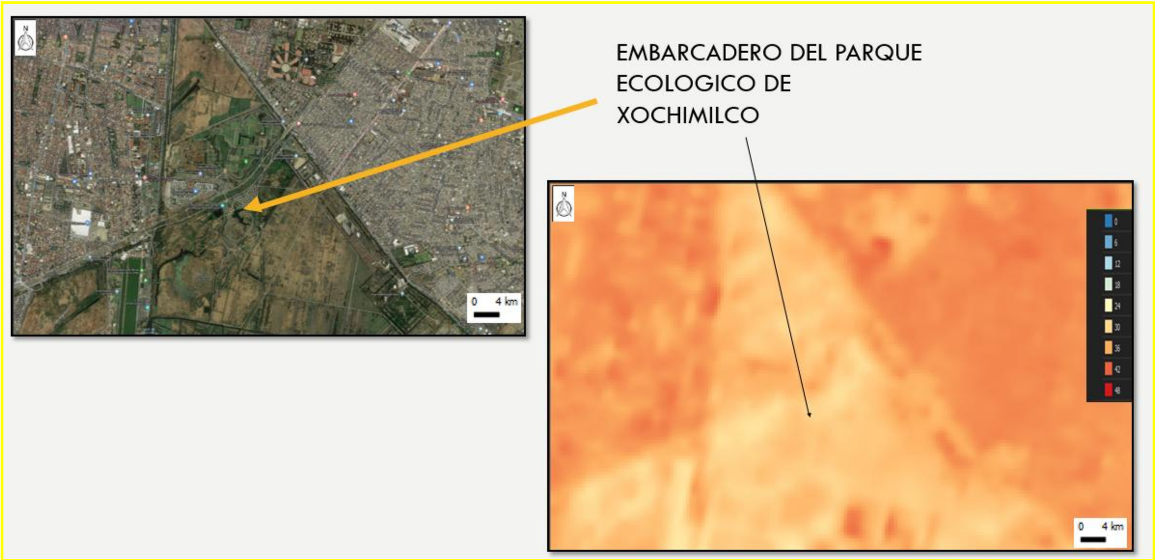


Figure 9: contrast in temperature data from Landsat 8 [5] and processed with the Qgis software which shows the contrast in temperature between the urban area and the rural area of the pier at the Xochimilco Ecological Park for the 18 May 2018.

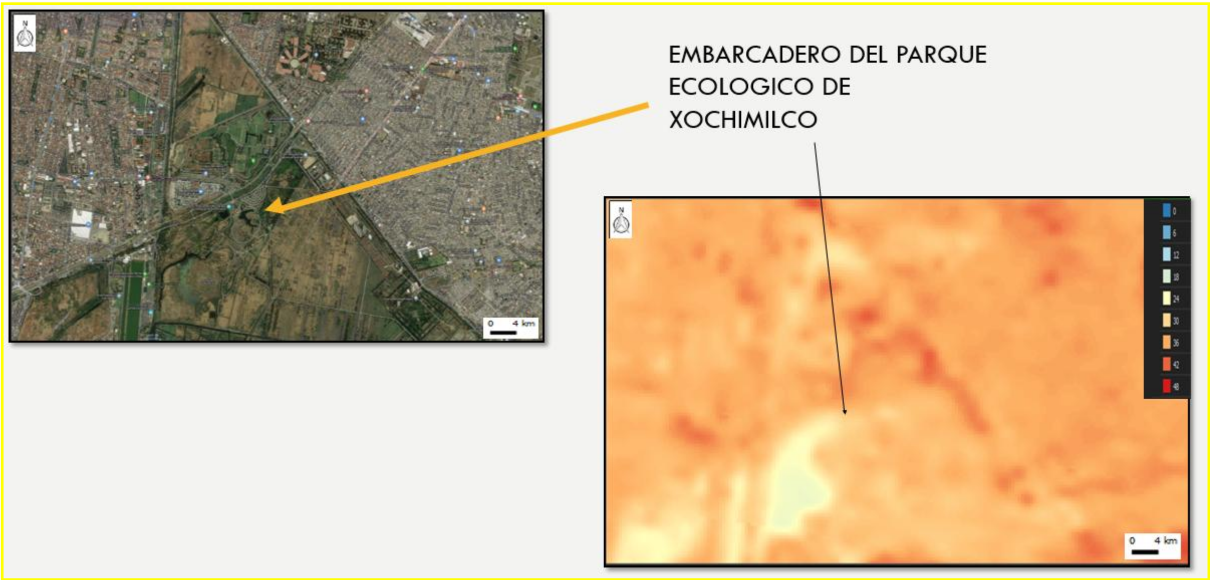


Figure 10: contrast in temperature data from Landsat 8 [5] and processed with the Qgis software which shows the contrast in temperature between the urban area and the rural area of the pier at the Xochimilco Ecological Park for the 11 May 1998.

We can observe that for the year 1998 the contrast in temperature between urban and rural areas was not as significant as opposed to the year 2018 where we can see even the decrease of the body of water from the

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pier in Xochimilco. Showing that the agglomeration of buildings dramatically increases the temperature increase by encouraging the development of heat islands in Mexico City.

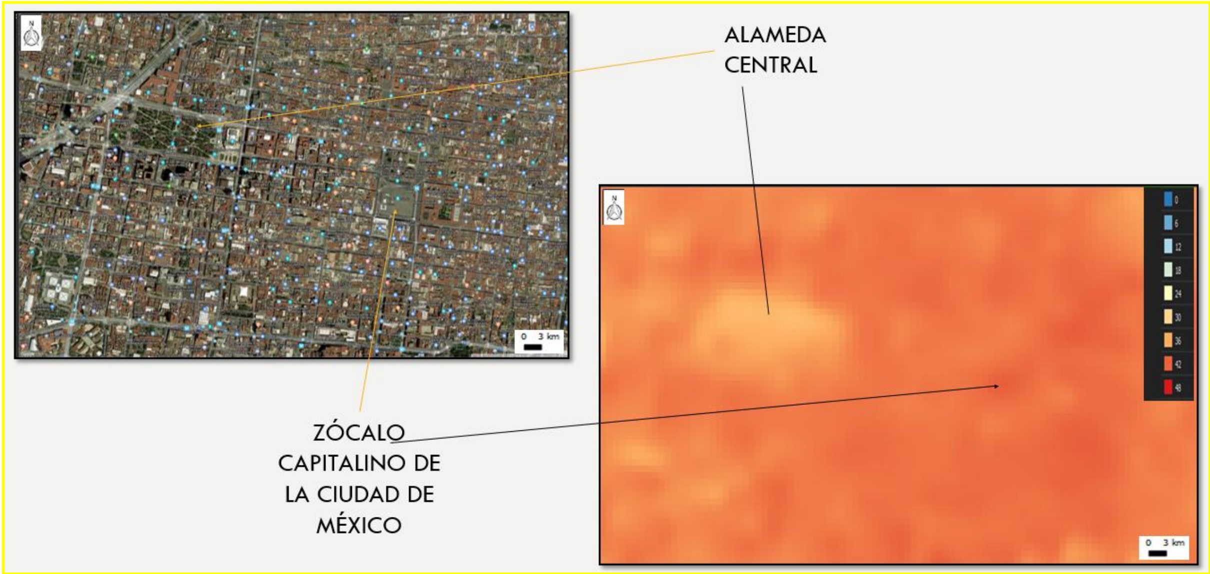

Figure 11: contrast in temperature data from Landsat 8 [5] and processed with the Qgis software which shows the contrast in temperature between the Alameda Central and the Zócalo in Mexico City for 18 May 2018.

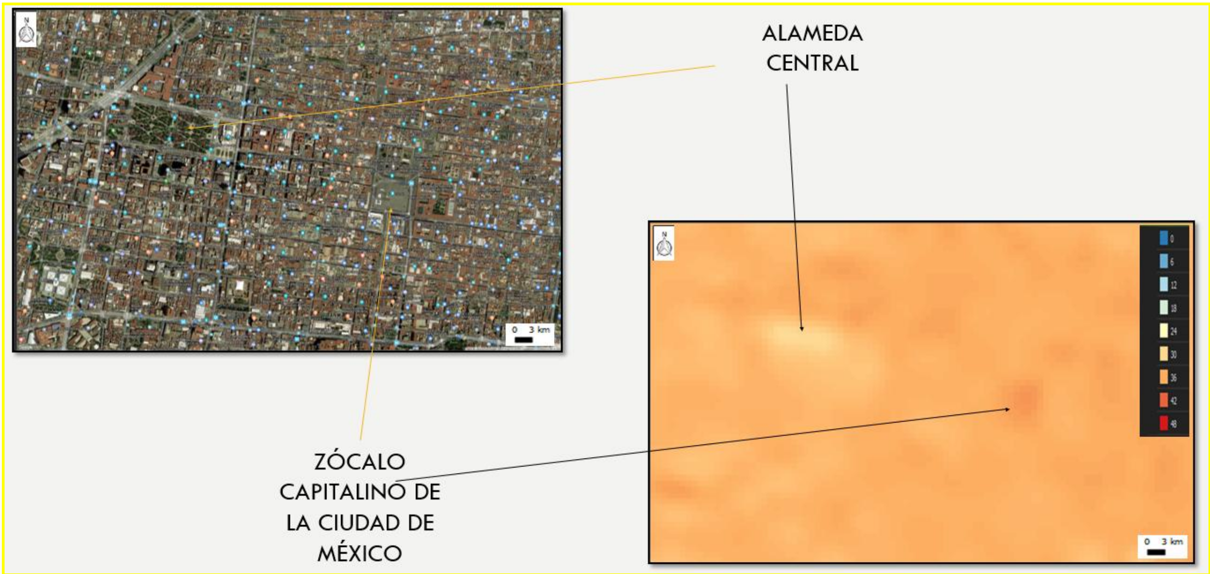

Figure 12: contrast in temperature data from Landsat 8 [5] and processed with the Qgis software which shows the contrast in temperature between the Alameda Central and the Zócalo in Mexico City for 11 May 1998.

It is noted that for the year of 1998 in the area of the Alameda Central and the Zócalo in Mexico City the contrast of temperature with their surrounding environment is not as significant as opposed to the year 2018 where temperatures surrounding the Alameda Central show values on the order of 35°C and above of this as well as to the zócalo which presents temperatures on the order of 39°C. Showing that the agglomeration of buildings dramatically increases the temperature increase by encouraging the development of heat islands in Mexico City. This analysis is performed to different points in Mexico City where we can observe the contrast in temperature between the urban area, parks and rural areas getting more and more indicative of the presence of heat islands in the City.

CASSEROLE EFFECT IN MEXICO CITY

Arises when the hot air that absorbs the city, coming from the atmosphere, moves in the environment in search of a natural outlet and the only escapes that are rural areas, adjacent to the metropolis, so it is directed to those regions and that heat damaged, dry, and desertification the green lungs that form the green belt of the city [9]. Physical phenomenon that affects most of the cities of the world, such is the case of Mexico City.

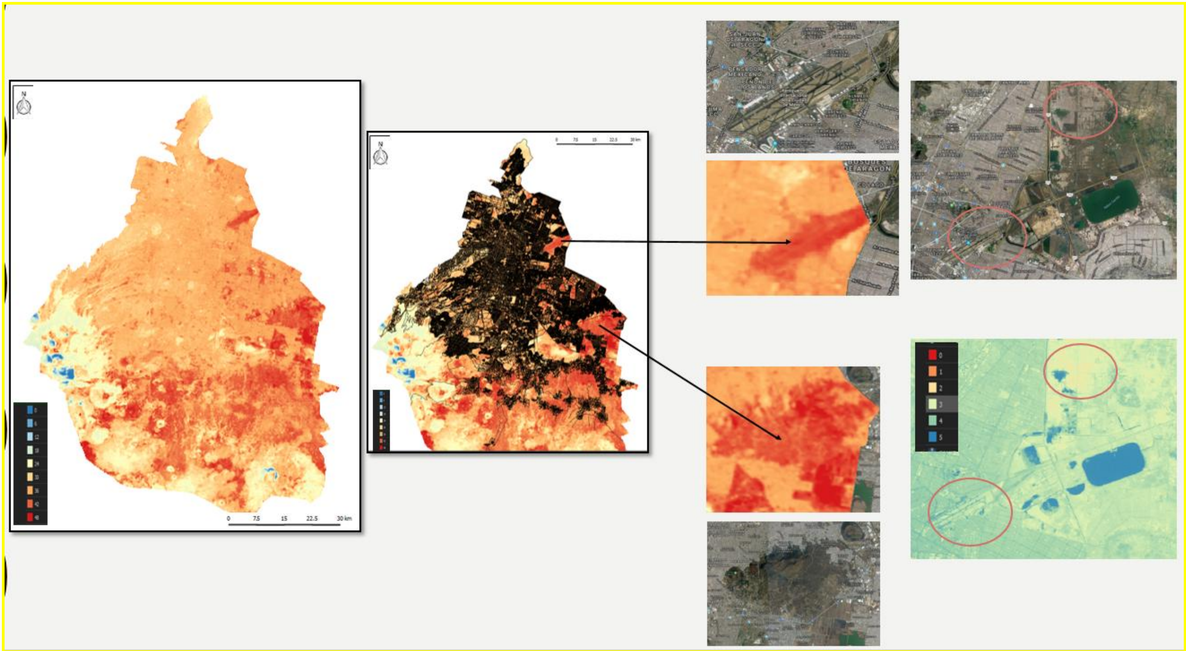

Figure 13: Determination of the effect pan in the Mexico City International Airport for 11 May 1998 from the analysis of temperature distribution provided by images of Landasat 8 [5].

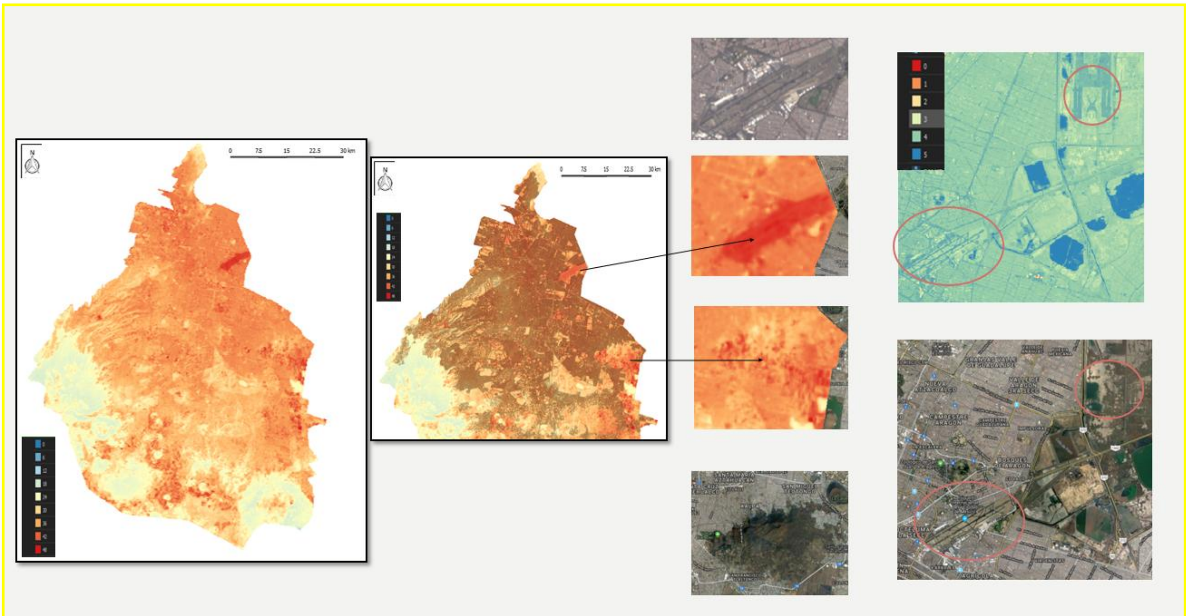

Figure 14: Determination of the effect pan in the Mexico City International Airport for 18 May 2018 from the analysis of temperature distribution provided by images of Landasat 8 [5].

In the previous analysis we can notice the effect pan and the consequences that it leaves in its wake, the hot air migrates to rural areas of the state of Mexico creating desertification and considerable damage to vegetation. Specify at the airport as in its limits is the lake of Texcoco, which is mainly composed of sedimentary deposits is a lacustrine environment with presence of water almost the whole year and therefore abundant nature; however, as a result of the effect Casserole is damaged and destroy the area. As well as happens in Lake Texcoco in different points analyzed around the metropolitan area of Mexico City this physical phenomenon persists.

WITH REGARD TO THE DEVELOPMENT AND INTENSIFICATION OF SEVERE STORMS

Mexico for its geographical location is frequently hit by extreme weather events such as hurricanes, tropical cyclones, heat waves, among others. To the east of the nation we find the Gulf of Mexico and to the west the Pacific Ocean, as a result of this in the rainy season the city of Mexico presents great moisture from fostering the development of storms. This tends to be a natural phenomenon common however in the last decade, the development of the storms seems to be growing, even allowing for the formation of the same within the city of Mexico phenomenon that had never before witnessed. The city now suffers from floods a lot of this has to do with its architectural design and where however from the point of view of Meteorology has noticed that rainy periods tend to be longer and that storms tend to park in a venting area most of its potential for rain in that area causing floods and waterlogging in the city.

Once you have defined the presence of heat islands is a possible relationship they have with the development and intensification of severe storms demonstrating that the islands of heat to the below a storm the supply of energy generating this park over the area of heat island. However, not only heat islands cater to the storms of energy if not that exist the ideal conditions of humidity and sufficient energy causes it to generate new nuclei of storm in areas where the areas of rain coming from the ocean by checking with the creation of new storms within the City of Mexico. To display the behavior of this phenomenon is analyze rainy days where you have present heat islands and the entry of storms coming from the ocean.

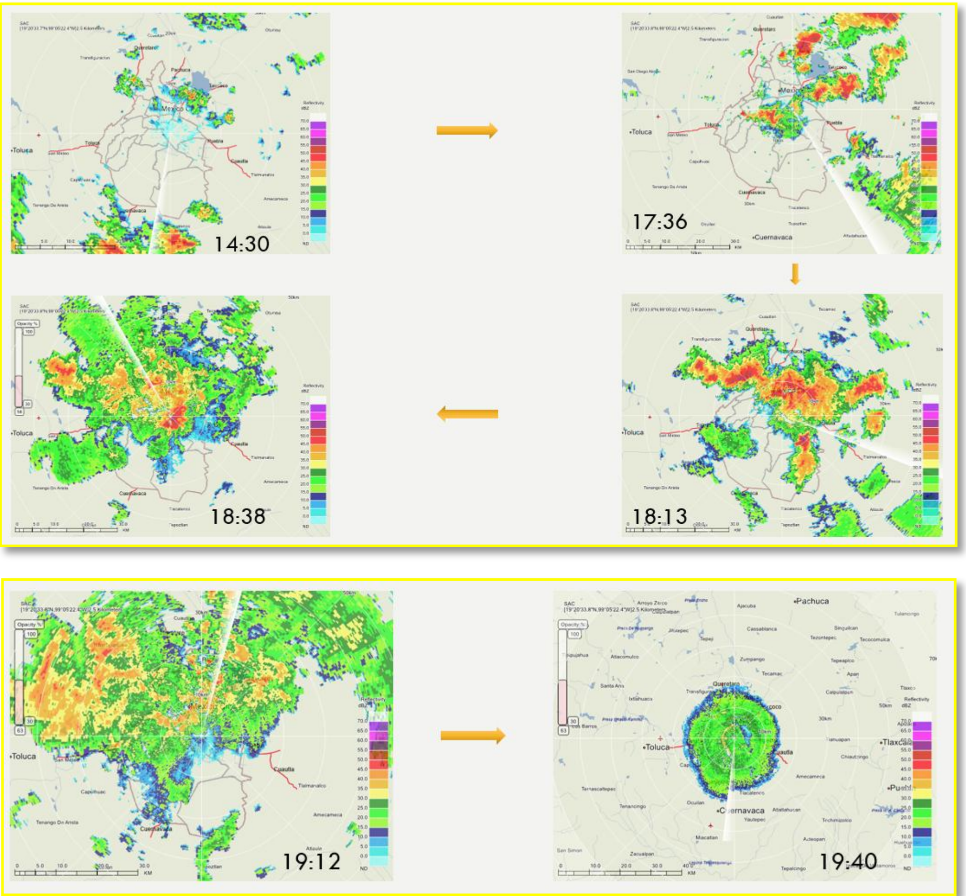

Figure 15: Storm of the day 15 August 2018 analyzed from the Weather Radar of the Mexico City [4].

Before the day 15 of August of this year. The presence of rain had been minimal i.e. two days before this rain present for the city was mild to advocate that the heat island was present until 15 August. In the images, we have noted that the 14:30 central time for Mexico cores are present storm dominated by the color red, for the 17:36 we observe new kernels of storm in the north of the city, to the 18:13 has already formed a line of storm that by definition this tends to follow a trajectory of wiping therefore it would be expected that they did throughout the city following a path NE-SW, for the 18:38 We note that the storm has stopped in the center and north of the city as a result of the heat island leaving behind the expected trajectory, for 19:12 the storm continues to parked in the center and north of the city and to the 19:40 the storm has covered a large part of the city. Showing that the passage of the storm the heat island the supplies of energy causing this park.

To strengthen this research continues to analyze the relationship they have storms with heat islands by following these with the help of meteorological radar of Mexico City from the month of August with the purpose of finding more evidence of this. It has been proven as heat islands tend to be dynamic and that not all the time will occur in the same place this due to the migration of the warm air toward rural areas. Which we will observe below.

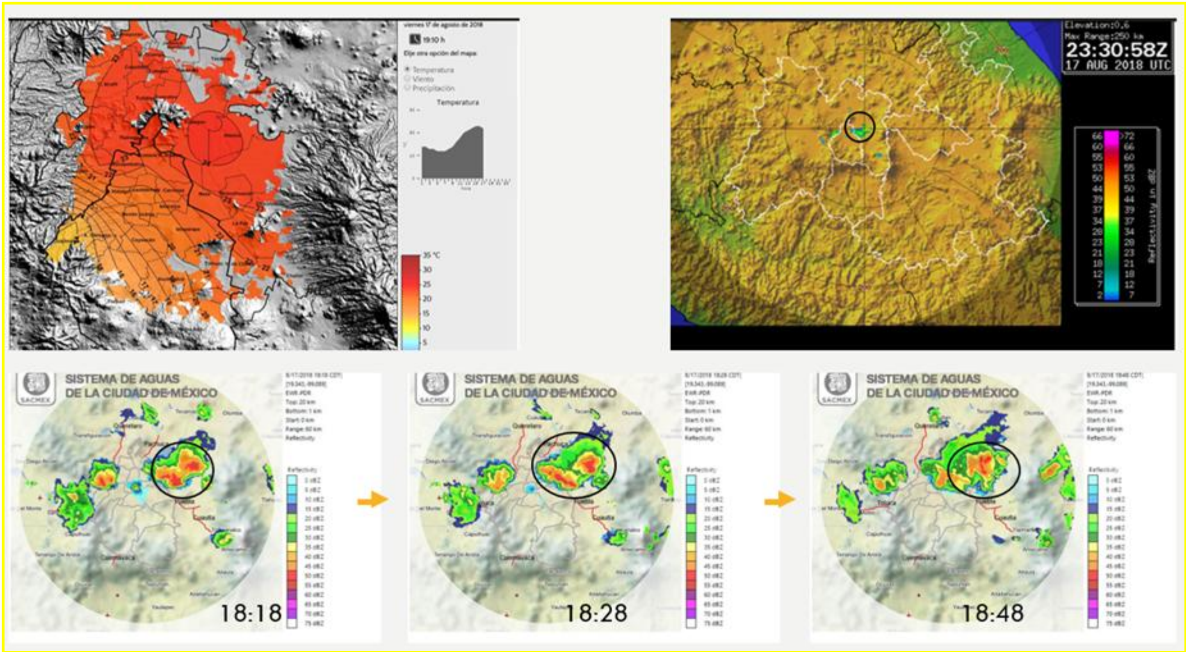

Figure 16: Storm of 17 August 2018 analyzed from the Weather Radar of the Mexico City [4] in comparison with map of surface temperature of the Air Quality [3] and the Weather Radar of the SENEAM [10].

As can be seen in the previous analysis we observe that the heat island is present in the area NE of Mexico City this to 19:30, 18:30 The radar of SENEAM [10] detects an area of storm in that same direction, for 18:18 The radar of Mexico City detects cores of storm NE of the City, for the 18:28 is still present the core of storm parked just in the heat island and to the 18:48 half-hour after the storm continues to parked at that point sourcing of energy and precipitating in that area leaving important values of rain to the NE of Mexico City.

The analysis has been repeated time and again in order to give certainty to this first relationship getting good results, however, continues to be worked in order to observe how is that this phenomenon behaves throughout the atmosphere and that other factors could be influential for the development and intensification of severe storms in Mexico City.

CONCLUSION

With the development of the previous job everything points to the fact that Mexico City is really affected by existence of heat islands. It is believed the existence of this physical phenomenon, since according to the echo analysis on a large and small scale maps of temperature distribution of Landsat data [5] and interpreted in Qgis show temperature contrasts in rural and urban areas is high unlike the data taken into earth leading us to think about the existence of heat islands. In addition, it verifies that the 9 May 1998 remains a landmark for the City of Mexico reporting a maximum temperature of 33.9° C in the observatory of Tacubaya, so they are able to detect the damage to vegetation that is inside and outside of Mexico City, which is attributed to the presence of this physical phenomenon.

The analysis of remote perception from Landsat 8 satellite images [5] allows us to find the possible relationship that exists between the islands of heat and the development and intensification of severe storms in the city of which we are still working to improve the results in order to raise awareness of physical phenomena that live in the city and better yet how to contribute to these decrease by mitigating the risk of a preventive way.

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