# Land classification, land surface temperature and normalized difference vegetation index using modis - a case study in Madrid, Spain

## Temperatura y clasificación del suelo, relación con el índice de vegetación normalizada usando modis - estudio de caso en Madrid, España

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### Abstract

The purpose of this study was to use the MODIS products in order to analyze and correlate Land Classification (MCD12Q1), Land Surface Temperatures (MOD11A2) and Normalized Difference Vegetation Indices (MOD13A2) in the City of Madrid and its surrounding areas, in order to validate the concept that remote sensing is a useful tool to develop guidelines on urban and territorial planning. Results show that the 42% of the area that surrounds Madrid has been designated for croplands while the rest of the area has been designated for woody savannas (19.84%), open shrublands (15.50%) and grasslands (7.77%). At the same time, results present the high correlation that all of the MODIS products have, based on the seasonal changes of the Land Surface Temperatures and the Normalized Difference Vegetation Indices.


**Keywords:** MODIS, Land Classification, Land Surface Temperature, Normalized Difference Vegetation, Remote Sensing.


### Resumen

El propósito de este estudio es usar los productos de MODIS para analizar y correlacionar la clasificación del suelo (MCD12Q1), la temperatura de la superficie de la tierra (MOD11A2) y los índices de diferencia de vegetación (MOD13A2) en la ciudad de Madrid y sus alrededores, con la finalidad de validar el concepto de que los sensores remotos son una herramienta útil a la hora de desarrollar guías para la planeación territorial. Los resultados muestran que el 42% del área alrededor de Madrid han sido designada para cultivo mientras que el resto del área ha sido designada para Sabanas arboladas (19,84%), matorrales abiertos (15,50%) y praderas (7,77%). Al mismo tiempo, los resultados presentan la alta correlación que tienen todos los productos MODIS, basados en los cambios estacionales de la temperaturas de la superficie terrestre y los Índices de diferencia en la vegetación normalizada.


**Palabras clave:** MODIS, Clasificación del suelo, temperatura superficial del suelo, diferencia normalizada de vegetación, Sensores Remotos.

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*El autor declara que no tiene conflicto de interés.*

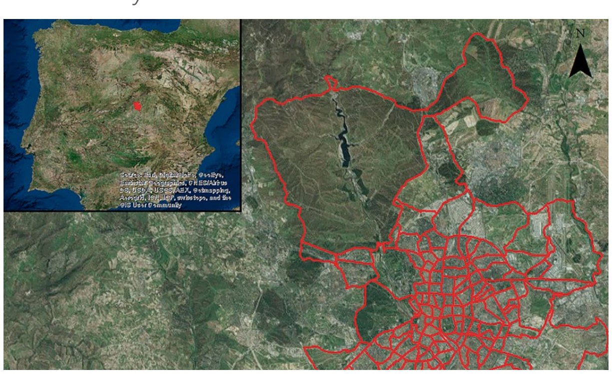
## Study area

The area of research for this project is the city of Madrid (Figure 1). Madrid is the capital city of Spain. This city is located at the geographic center of the Iberian Peninsula (40°24'59"N, 03°42'09"W), surrounded to the north by Sierra de Guadarrama and to the west by Sierra de Gredos [1]. Madrid has an average elevation of 650 meters above the sea level, the highest elevations of the city can be found in the north, where elevations can reach up to 700m. While the lowest elevations of the city can be found in the southeast portion, where elevations reach a maximum of 600m [2].

Madrid has four well defined climatological seasons (winter from December to February, spring from March to May, summer from June to August and autumn from September to November) [1], but the city and its surroundings present a Mediterranean climate [4], which is characterized by "hot, dry summers and cool, wet winters" [4]. The annual average temperature of Madrid is 14 °C, which is 0.6 °C above the county annual average (14.6 °C). The hottest temperatures normally occur during summer, when they can reach up to 40 °C, while the coldest readings typically take place during winter, when they go as low as 2 °C [1]. On average, the annual precipitation in the city is 436 mm, with maximum values occurring in the months of November and December (56 mm/month) and lowest values in July and August (10 mm/month).

In terms of population, based on the last census performed in 2011 by the "Instituto Nacional de Estadistica" (National Institute of Statistics) (INE) of Spain, Madrid has 3,198,645 people (1,495,337 males, 1,703,308 females), which accounts for 7% of the total population of Spain. For the purpose of this project, a 200 km by 200 km around the City of Madrid was selected.

***Figure 1.*** *Overview of the City of Madrid (white). The divisions represent the different zone distribution inside the City.*



*Fuente: Propia del Autor*

## Data collection

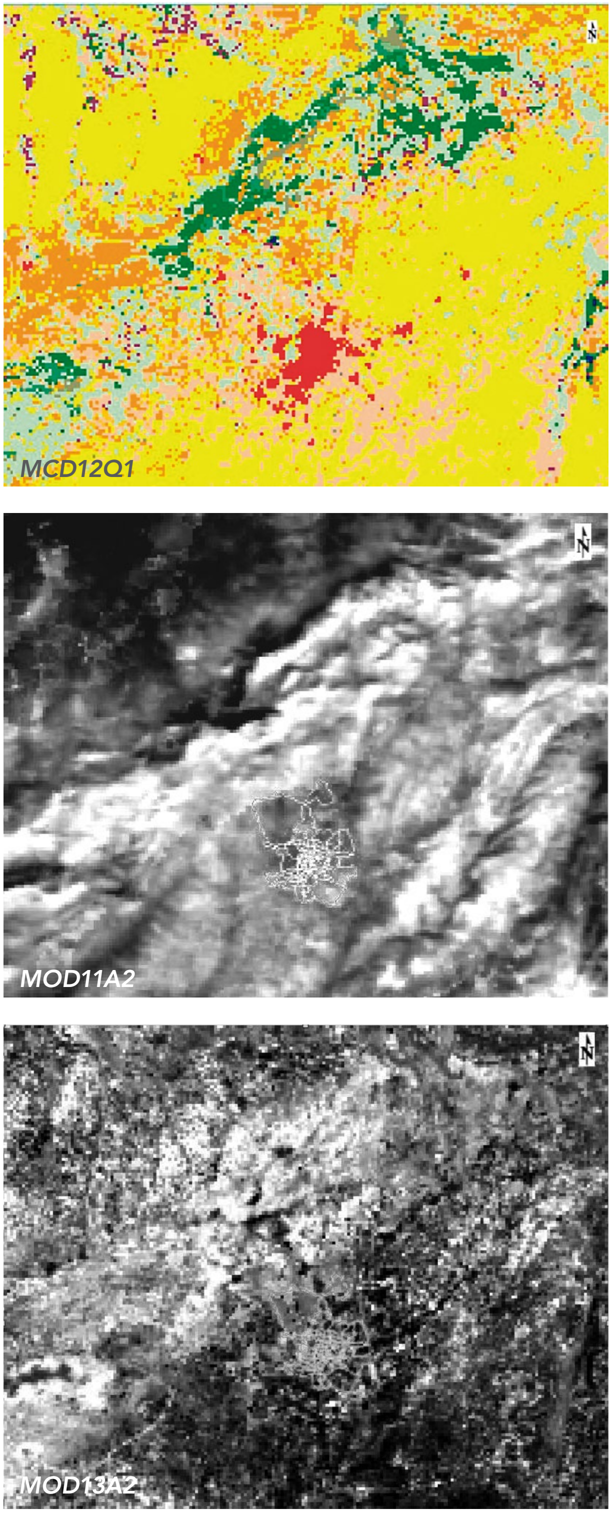
For the purpose of this project, three Moderate Resolution Imaging Spectroradiometer (MODIS) products where used; MODIS Land Cover Type (MCD12Q1) (Figure 2-A), MODIS Land Surface Temperature (MOD11A2) (Figure 2-B) and MODIS Vegetation Indices (MOD13A2) (Figure 2-C). These products used a combination between Aqua and Terra data.

Aqua (or EOS PM-1) is a mission launched by the National Aeronautics and Space Administration (NASA) on May 4, 2002. Its main purpose is to collect data about the Earth's water cycle (precipitation and evaporation) in the ocean, atmosphere, clouds and ice/snow-covered soils [5]. Onboard, Aqua has six Earth-observing instruments: Advanced Microwave Sounding Unit (AMSU), Atmospheric Infrared Sounder (AIRS), Cloud and the Earth's Radiant Energy System (CERES), MODIS, Humidity Sounder for Brazil (HSB) and Advanced Microwave Scanning Radiometer (AMSR-E).

Terra (or EOS AM-1) is a mission launched by NASA on December 18, 1999. Its main purpose is to collect information about energy, carbon and water in the clouds, air-land and air sear around the earth [6]. Onboard, Terra has five Earth-observing instruments: Advanced Spaceborne Thermal Emissions and Reflection Radiometer (ASTER), CERES, Multi-angle Imaging Spectroradiometer (MISR), MODIS and Measurement of Pollution in the Troposphere (MOPITT).

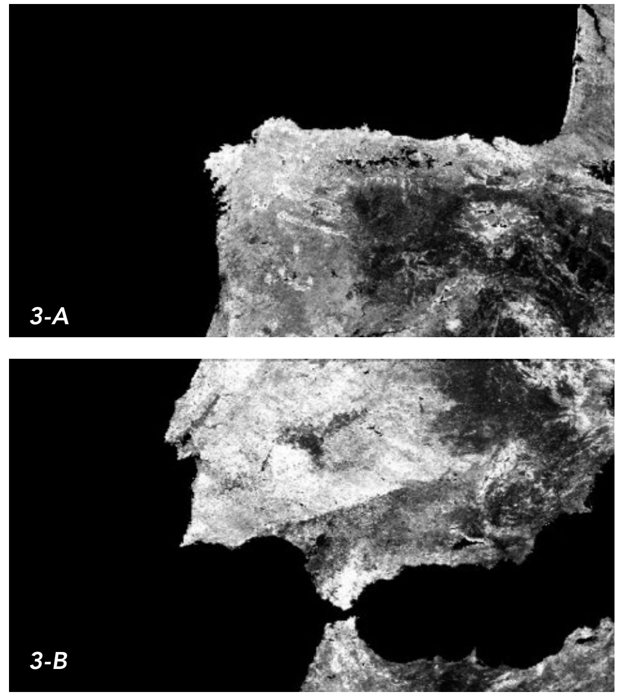
In order to map the area of interest (City of Madrid), tile V05_H16 and tile V04_H17 were obtained using the IDL 8.5 custom made software. Two tiles were needed, because the City of Madrid is located on the South portion of tile V04_H17 (Figure 3-A). This means that all of the surrounding area to the South East, South and South West of the city is missing. So in order to have a complete picture of the surrounding areas around Madrid, a second tile (V05_H16) was needed (Figure 3-B).

***Figure 2.*** *200 km x 200 km view of the MODIS products; MCD12Q1, MOD11A2 and MOD13A2 for the City of Madrid (Red) and its surroundings.*




*Fuente: Propia del Autor*

***Figure 3.*** *MOD13A2 V04_H17 tile (3-A) and MOD13A2 V05_H16 tile (3-B). In red the City of Madrid located to the South of tile V04_H17.*




*Fuente: Propia del Autor*

# Methodology

## Image Processing (Mosaic, Resize and Subset)

In order to process the images obtained from MODIS, ENVI 5.3 was used. The first step taken in this process, consisted in mosaicking all of the 6 images (2 images per MODIS model from each tile) into three single images that combined the two tiles. In order to do that the Seamless Mosaic tool from the ENVI toolbox was used.

Once the mosaic of the images was completed, it was necessary to resize the mosaicked Land Classification (LC) (MCD12Q1) image; given that the spatial resolution of this product is 500 m by 500 m while the spatial resolution of the Land Surface Temperature (LST) (MOD11A2) and the Normalized Difference Vegetation Index (NDVI) (MOD13A2) product is 1000 m by 1000 m. This resizing was performed using the Resize Data tool, where the input for the samples and lines was established as 1200 by 1200. Finally a 200 km by 200 km subset was created from the images.

## Land Classification (LC)

The LC product is a global product that identifies 17 different land cover classes (11 natural vegetation, 3 developed and mosaicked and 3 non-vegetable) defined by the Geosphere Biosphere Programme (IGBP) [7,8]. The first step in processing this product, was to define the classes in the header file, by adding the classes, class names and the class lookup information to the .hdr file of the image (Appendix A). Once that was completed, the percent of area in each class on the subset was calculated.

## Land Surface Temperature (LST)

The LST MOD11A2 product is a product that presents average global surface temperatures [7,9]. The first step in processing this product was to change the temperature data from its original number to Celsius. This was performed using the Band Math tool in ENVI. Once that was completed, the statistics for Woody savannas, Croplands, and Open shrublands (three largest classes in the subset besides urban) were obtained. The second step was to create maps for the month of January and July (subtracting the average urban temperature), by using the Band Math tool and changing the color slices.

## Normalized Difference Vegetation Index (NDVI)

The NDVI MOD13A2 product is a global product that determines daily vegetation indices using the blue, red and near-infrared bands [7, 10]. The first step in processing this product was to obtain the statistics for Woody savannas, Croplands, and Open shrublands (least green classes in the subset besides urban). The second step was to create maps for spring, summer and fall (subtracting the average urban NDVI), by using the Band Math tool and changing the color slices.

# Results

## Land Classification (LC)

Figure 4 present the LC classification of Madrid and its surrounding area. As stated on the methodology, these classes were defined by changing the header file of the images. By doing this, a class name was defined (Woody savannas, Croplands, Open shrublands, etc.), and at the same time a refraction value was assigned to each class name (same concept as a supervised classification).

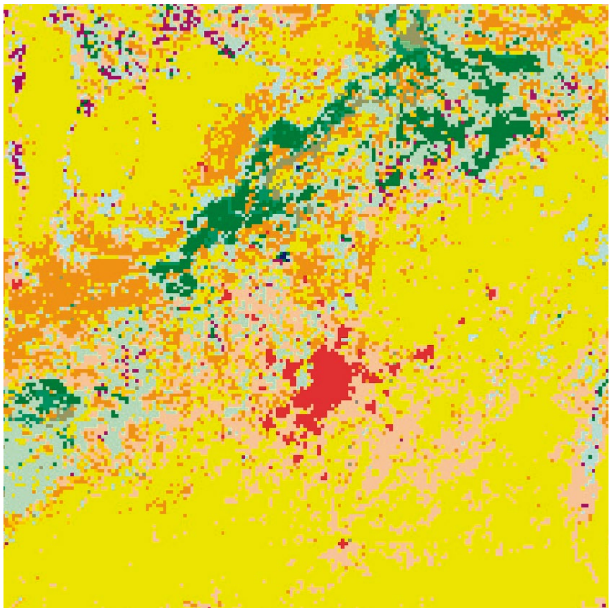
From Figure 4 it can be observed that the area around the City of Madrid (Red), is mainly surrounded by croplands (Yellow). Table 1, presents the percentage distribution and the pixel count of the defined classes in study area. From this table it can be identified that the majority of the area follows under the "Cropland" class (42%) while the actual City of Madrid only represents a 0.30% of the total area encompassed by this image. At the same time it can be identified that "Woody savannas" and "Open shrublands" account for 36% of the LC (20% and 16% respectively), while the remaining 22% accounts for the rest of the classes.

***Table 1.*** *Distribution of the land cover classes in Madrid and its surrounding area.*

| Class Summary | Pixel Count | Percent |
|---|---|---|
| Croplands | 604159 | 41.96 |
| Woody savannas | 285764 | 19.84 |
| Open shrublands | 223259 | 15.50 |
| Grasslands | 111874 | 7.77 |
| Savannas | 109148 | 7.58 |
| Evergreen Needleleaf forest | 39836 | 2.77 |
| Mixed forest | 27458 | 1.91 |
| Cropland/Natural vegetation mosaic | 24179 | 1.68 |
| Closed shrublands | 7799 | 0.54 |
| Urban and built-up | 4390 | 0.30 |
| Water | 1080 | 0.08 |
| Deciduous Broadleaf forest | 637 | 0.04 |
| Barren or sparsely vegetated | 242 | 0.02 |
| Permanent wetlands | 127 | 0.01 |
| Deciduous Needleleaf forest | 42 | 0.00 |
| Evergreen Broadleaf forest | 6 | 0.00 |
| Snow and ice | 0 | 0.00 |
| Unclassified | 0 | 0.00 |
| Fill Value | 0 | 0.00 |

*Fuente: Propia del Autor*

*Figure 4. for the City of Madrid (Red) and its surrounding areas.*



*Land Surface Temperature (LST)*

Figure 5 present the LST of the three largest classes (Woody savannas, Croplands, and Open shrublands) and the Urban and built-up class. From this figure, it can be observed how the four classes were subjected to temperature modifications, based on the seasonal changes. This means that each class increased or lowered its temperature based on the time of the year. For example, by looking at the "Urban and build-up" class, one can notice that during the first period of the year (composites 1-6 middle or end of winter) the temperature ranges from 8 to 10 °C, then from that point on it increases up to a maximum of 45 °C (composite 25 middle of summer) and then from that point on it decreases back to around 8 to 10 °C (composite 46 begging of winter).

At the same time, it can be observed that during the entire year the Woody savannas is the class that in average has the lowest temperatures (22 °C), followed by Urban and build-up (25 °C), Croplands (25 °C), and Open shrublands (26 °C). This phenomenon can be explained, by the fact that Woody savannas have trees and tress provide shade, which can cool down the area. While the Open shrublands are openly expose to the heat, with no structures that provides shade or keeps the surface cool.

*Figure 5. Day time temperatures comparison between the three largest areas and urban*

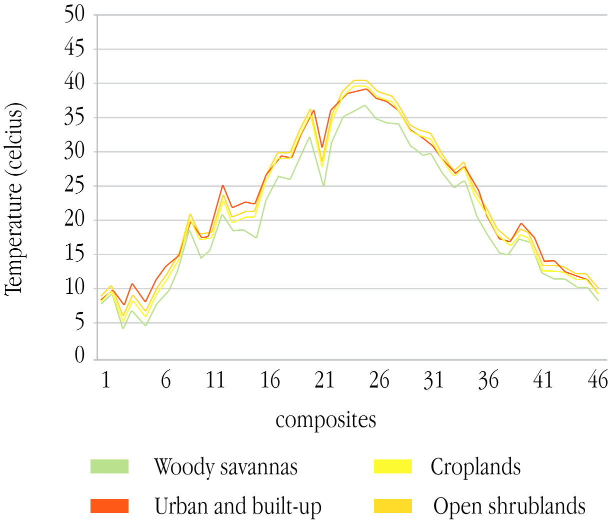
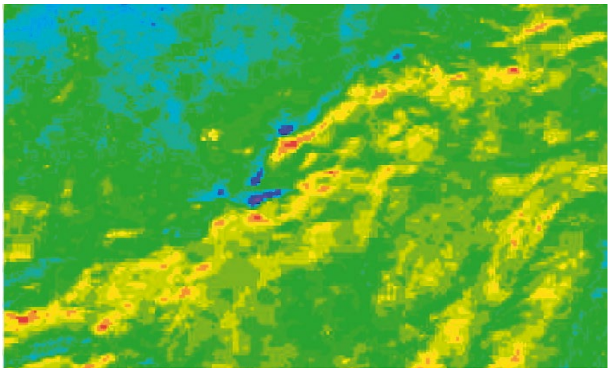
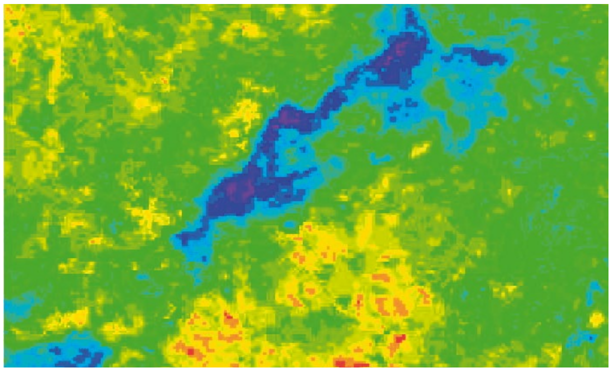



*Figure 6. Temperature moth on January*



*Fuente: Propia del Autor*

*Figure 7. Temperature moth of July*



*Fuente: Propia del Autor*

Figure 6 and figure 7 present the LST for the month of January and July respectively. Form this figures it can be observed how the temperature around the area changes depending on the season (same principle as the one described above). This phenomenon can be observed by the fact that during the month of July higher temperatures (orange and yellow color) have a higher presence in the figure (especially on the south portion of Figure 7).

## Normalized difference vegetation index (NDVI)

Figure 8 present the NDVI of the three largest classes (Woody savannas, Croplands, and Open shrublands) and the Urban and built-up class. From this figure, it can be observed how NDVI can not only be related to seasonality, but at the same time it can presents changes in practices or growing stages of certain classes (especially croplands). By looking at the urban and built up NDVI behavior from Figure 8, one can observed that the NDVI value of this class does not present a lot variation during the year; the reason for that is, because the city is mainly composed by concreted, asphalt or cement (material that do not have any type of chlorophyll in their molecular structure) so those materials do not experience any growth due to the interaction with the sun, so its value is relatively constant during the entire year.

However, by looking at NDVI behavior of croplands, one can observed that during the first period of the year (composites 0-10) this class increased its NDVI, but in the middle and final period (composites 10-23) that NDVI decreased. The reason for that, is because during the first portion of the year crops are growing (inclination of the NDVI) until they reach its maximum growth, then harvesting of those crops starts (declination on the NDVI) and them replantation of new crops take place (flat portion of the NDVI).

Following that same principle of seasonal growth dictated by change in temperatures, it can be observed from Figure 9 how the different classes (mainly woody savannas) around Madrid, increase their NDVI in the spring season (Figure 9-A) (they become more green because they start to growing) and as time passes those same areas start to lose their green, especially in the fall season (Figure 9-C) mainly because they die due to change in temperature (temperature decreases, so trees, plants and crops die).

***Figure 8.*** *NDVI comparison between the three largest areas and urban*

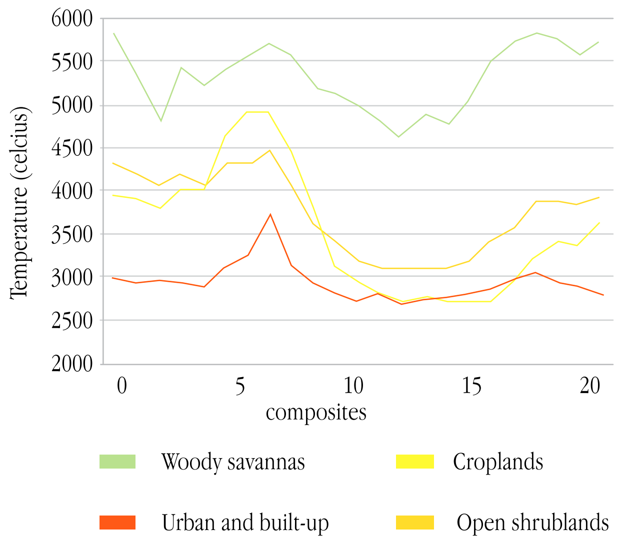
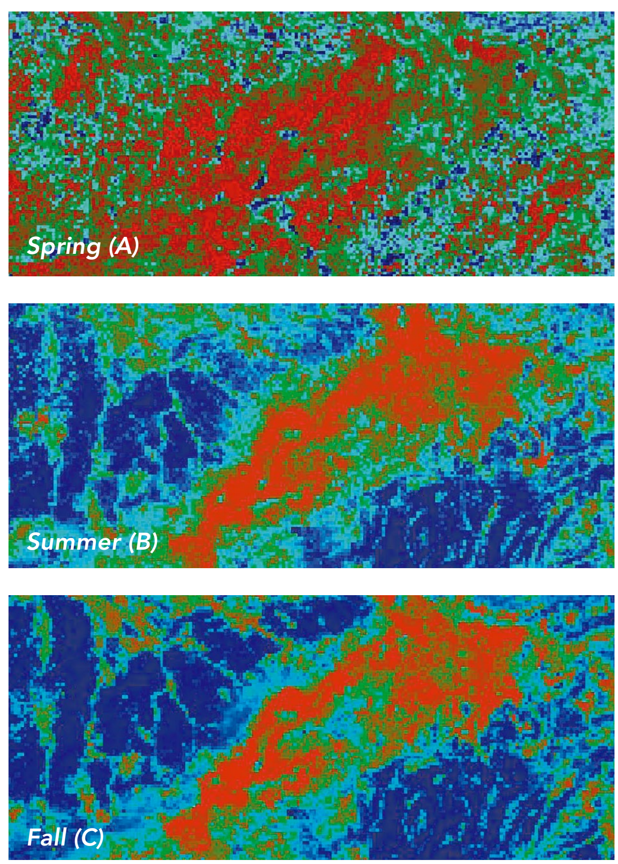



***Figure 9.*** *NDVI change for the spring (A), Summer (B) and Fall (C) season in the City of Madrid and its surrounding areas.*



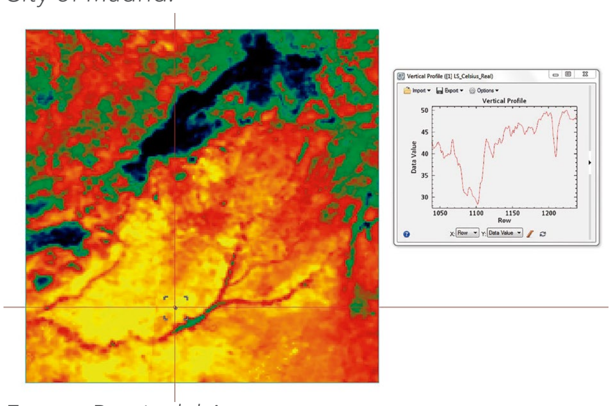

*Fuente: Propia del Autor*

# Distance analysis

## Temperature

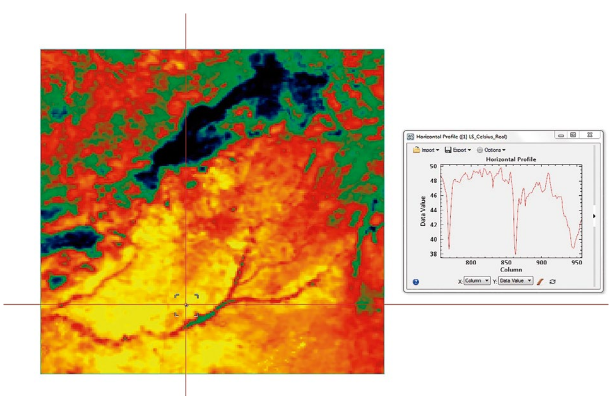
Figure 10 and Figure 11 present a temperature change in the vertical and horizontal direction respectively. This analysis was performed in order to see the difference in temperatures between the different areas as well as in the City of Madrid. For this analysis the month of July was selected in order to present that change.

***Figure 10.*** *Temperature vertical profile for the month of July. Black square represent the location on the City of Madrid.*



*Fuente: Propia del Autor*

***Figure 11.*** *Temperature horizontal profile for the month of July. Black square represent the location on the City of Madrid.*



*Fuente propia del Autor*

Figure 10 and Figure 11 are composed by two pieces. The first piece is the map that presents a graphical representation of the different temperatures around the area of study. The second piece is a table that presents the change in temperatures in the horizontal or vertical direction; the x-axis indicates the location in the map, while the y-axes indicates the temperature range.

From these two figures and its respective components/pieces, it can be observed how the temperature inside the City of Madrid (in the horizontal and vertical direction) are some of the highest temperatures that can be identified in the area (around 45 to 50 °C).

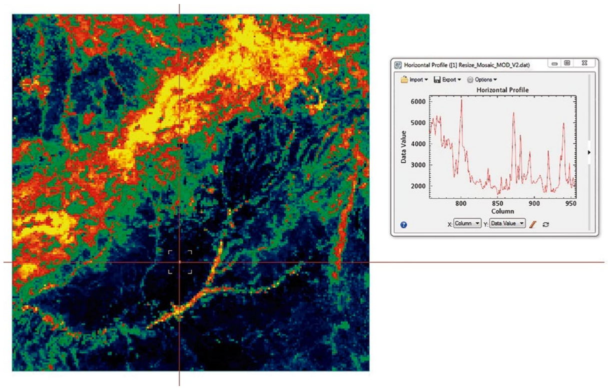
This phenomenon could be explained by the fact that the material of the structures that composes the city, has a huge potential to retain heat. At the same time and taken into account the information presented in Table 1 (Page 8), most of the area that surrounds the city is mainly croplands, which indicates that these areas are openly expose to the sun and given the composition of crops, there is not a lot of shade that they can generate by these structures.

## NDVI

Figure 12 and Figure 13 present the NDVI change in the vertical and horizontal direction respectively. This analysis was performed in order to see the difference in NDVI between the different areas as well as in the City of Madrid. For this analysis the month of July was selected in order to present that change.

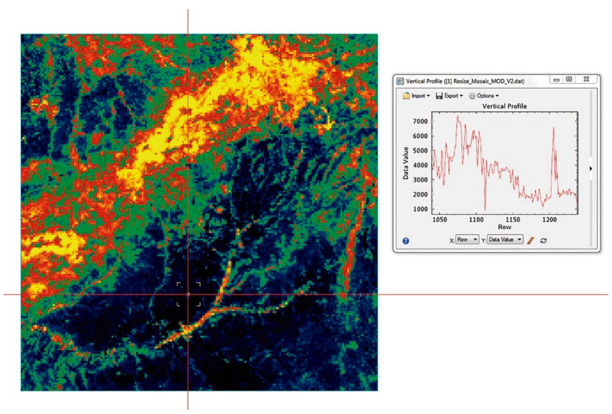
Figure 12 and Figure 13 are composed by two pieces. The first piece is the map that presents a graphical representation of the different NDVI values around the area of study. The second piece is a table that presents the change in NDVI in the horizontal or vertical direction; the x-axis indicates the location in the map, while the y-axes indicates the NDVI value. From these two figures and its respective components/pieces, it can be observed how the NDVI inside the City of Madrid (in the horizontal and vertical direction) are some of the lowest values that can be identified in the area (around 1000 to 2000). This phenomena, could be explain by the fact that the material of the structures that composed the city, does not get green as compared to croplands or trees. Which indicates that not only on this month, but also during the entire year, the NDVI values for the City of Madrid will be the lowest value if compared to classes that have the ability to growth and become green (have chlorophyll).

***Figure 12.*** *NDVI horizontal profile for the month of July. Red square represent the location on the City of Madrid.*




*Fuente: Propia del Autor*

***Figure 13.*** *NDVI vertical profile for the month of July. Red square represent the location on the City of Madrid.*




*Fuente: Propia del Autor*

## Conclusions

The main purpose of this study was to use the MODIS products in order to analyze and correlate Land Classification (MCD12Q1), Land Surface Temperatures (MOD11A2) and Normalized Difference Vegetation Indices (MOD13A2) in the City of Madrid and its surrounding areas. After completing this study it may be concluded that:

- 42% of the area that surrounds Madrid has been designated for croplands.
- Woody savannas and Open shrublands account for 36% of the LC (20% and 16% respectively). The remaining 22% accounts for the rest of the classes.
- Land Surface temperatures were subjected to temperature modifications, based on the seasonal changes.
- NDVI cannot only be related to seasonality, but at the same time it can present changes in practices or growing stages of certain crops/plants.
- Future studies need to be performed. However, it seams that the City of Madrid has secured its alimentary needs.

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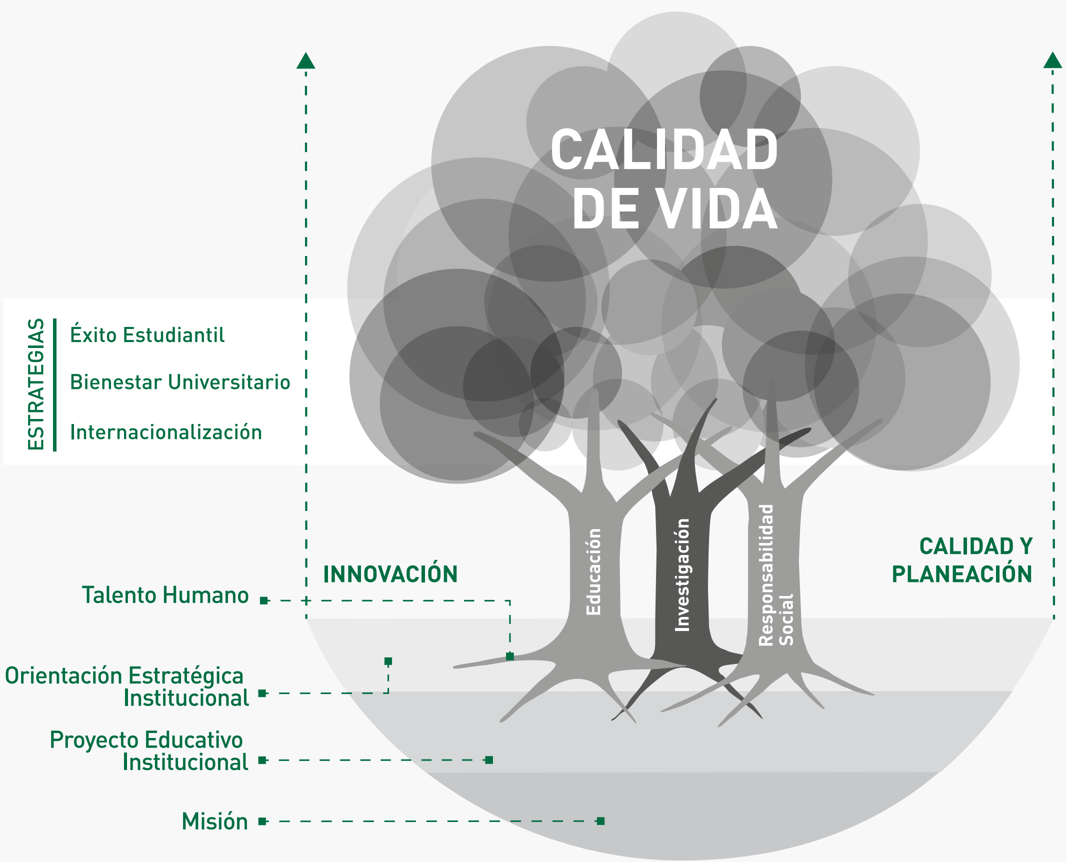


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