Burning up: Tracking the Urban Heat Island Effect in New York City from 1984-1999

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Data Sources: USGS Earth Explorer
Map Coordinate System and Projection:
WGS_1984_UTM_Zone_18N

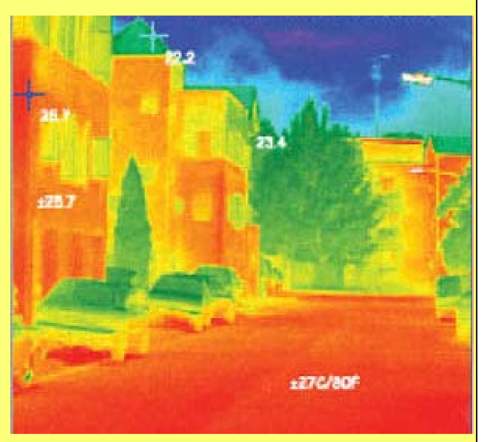
Background

Urbanization usually arises at the expense of vegetation when open space is converted to buildings, roads, and other infrastructure. Urban materials used to build these structures do not have the same thermal and radiative properties as vegetation, and as a result, can largely influence a city's climate. The loss of vegetation can increase surface and air temperatures directly through the loss of shade and indirectly through reduced rates of evapotranspiration. In addition, materials like concrete and steel have high heat capacities and lower solar reflectance. A higher heat capacity allows for increased storage of the sun's energy while a lower solar reflectance results in increased absorption of solar energy. The urban geometry of a city can increase surface temperatures as well by obstructing air flow and preventing cooling by convection.

When urbanized areas become warmer than their rural neighbors, the effect is known as the urban heat island effect (UHI). There are two different types of urban heat islands: surface and atmospheric. Surface heat islands occur when the sun heats up exposed infrastructure surfaces to temperatures 27 to 50°C warmer than the air. Atmospheric heat islands are defined by increased air temperatures in urban areas versus cooler air temperatures in rural areas. It is important to track changes in the UHI effect because it can result in increased energy demand and elevated emissions of air pollutants and green house gases as people try to counteract warmer temperatures.

Purpose

This project used the remote sensing technique of change detection analysis to quantify the changes in vegetation and urbanization in New York City over a 15 year period and compared these results to differences in the city's surface temperature. New York City was chosen as the study area because it is a large, densely populated city with heterogeneous land use, including residential areas, business districts, industrial areas, and few open spaces.

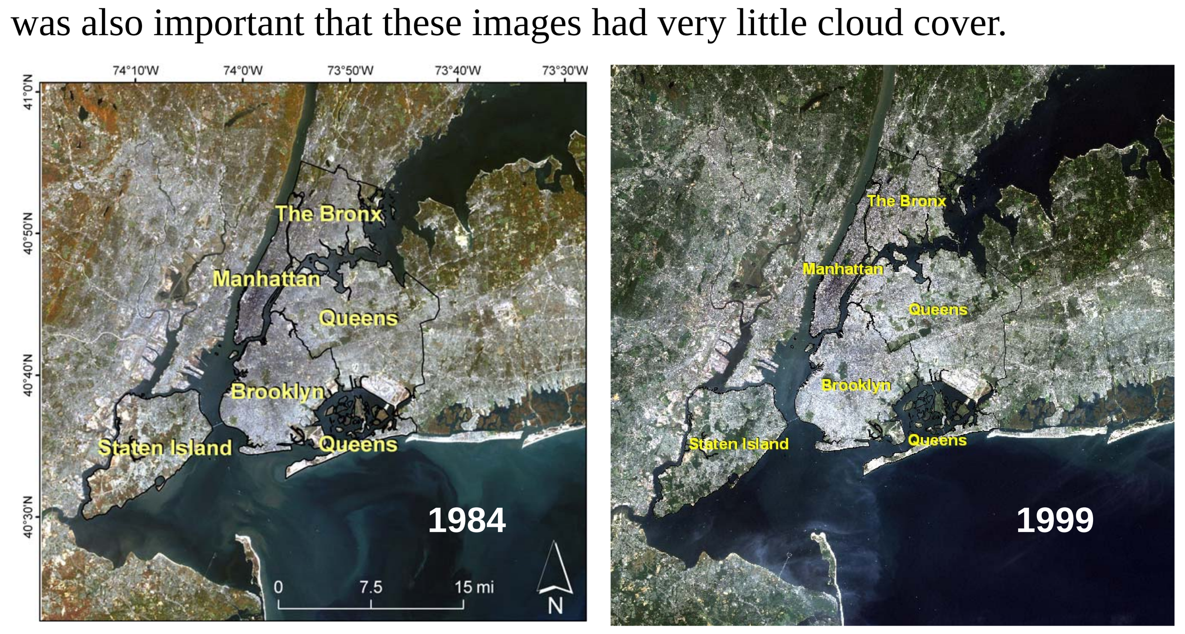


Essentially, this project attempted to determine whether or not the city experienced a surface UHI from 1984 to 1999 by finding a relationship between vegetation loss, an increase in urbanization, and an increase in surface temperature. If the Urban Heat Island effect occurred over the 15 years, there should be an overall spreading of warmer-temperatured areas and a general trend of warmer urban areas and cooler surrounding suburbs.

Methods

Image Collection for Area of Interest

The images of New York City were obtained from USGS Earth Explorer. The first image was taken by Lansdset 4-5 TM on October 16, 1984, had 0% cloud cover, and had a sun azimuth of 151. The second image was taken by Landset ETM+ on October 2, 1999, had 0.02% cloud cover, and had a sun azimuth of 154. In order to perform an accurate change detection analysis, it is important that the images were taken around the same day so that seasonal differences would not influence the results. It was also important that these images had very little cloud cover.



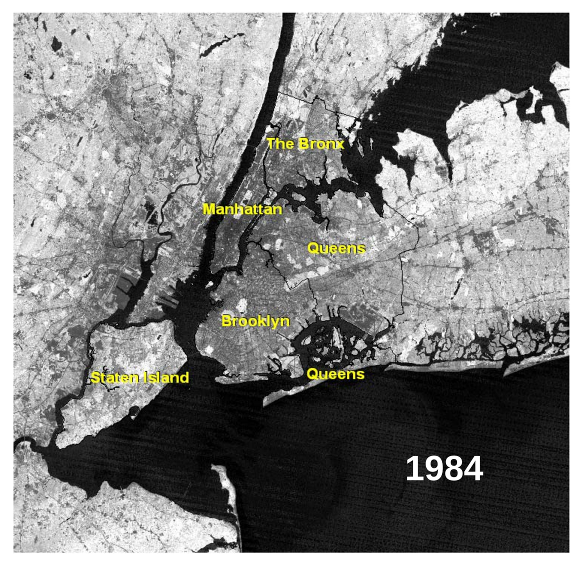
Preparing Images for NDVI and PCA

The images had to be stacked and adjusted so that band 6 (the thermal band) and band 8 (the panchromatic band) were removed. These bands were not needed for change detection analysis and could complicate the results if left in. The images were then clipped so that the focus was on NYC and its surrounding suburb areas. These actions were done using the Layer Stacking and Resize Data functions.

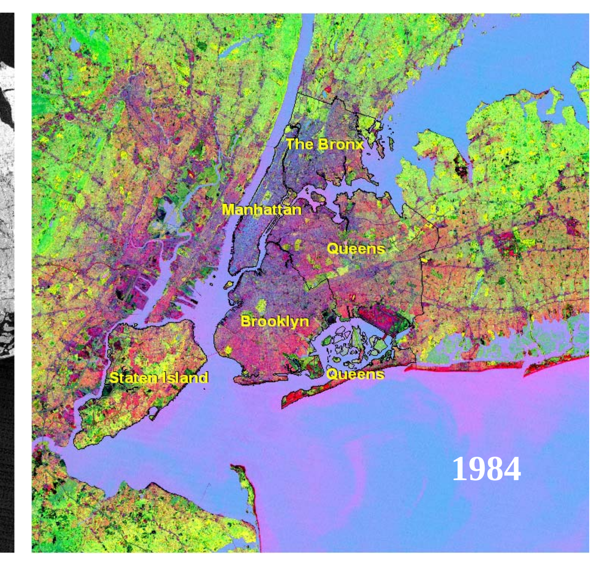
Normalized Difference Vegetation Index (NDVI) vs. Principle Component Analysis (PCA)

In order to eventually perform a change detection on vegetation and urbanization, the image pixels had to be separated into three classes: urban, vegetation, and water. However, before that could be done, NDVI and PCA preprocessing procedures were used to see which method reduced the greatest amount of noise and produced the most accurate classes for classification. At first, supervised classification was done on the NDVI and PCA images using 10 R.O.I.s for several subgroups of each class. The accuracy of this classification was too low to be used for the change detection analysis. Therefore, unsuperivsed classification was used on the NDVI images and the first 3 bands of the PCA images utilizing the K-means method and specifying 15 classes and 20 iterations.

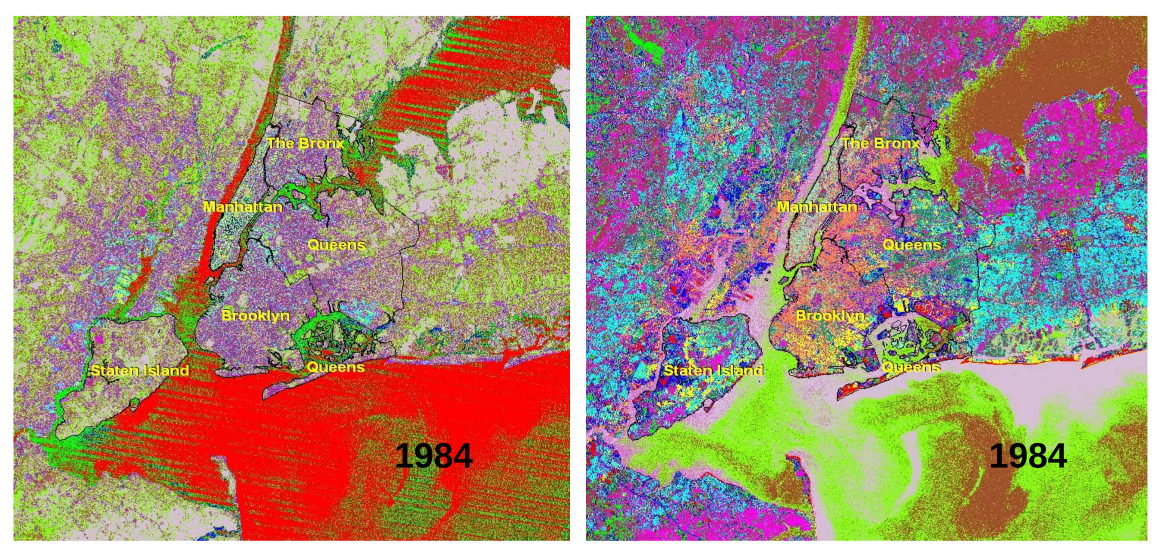
NDVI: Red: Band 3; Near IR: Band 4



PCA: Forward Minimum Noise Fraction Rotation



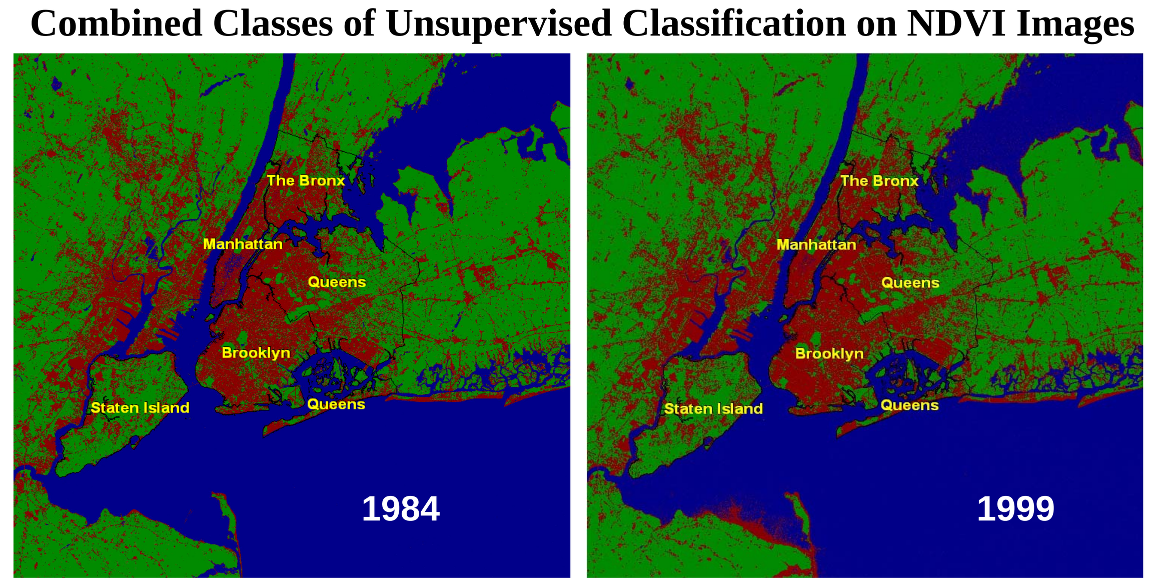
Unsupervised Classification: 15 Classes; 20 Iterations



Combining Classes to Prepare for Change Detection

Due to the complexity and noise of the PCA classification, the NDVI unsupervised classification images were chosen for the change detection analysis. By specifying 15 classes, the images were very detailed and showed varying levels of vegetation, water, and urbanization. Therefore, each subgroup had to be appropriately colored using the color mapping tool so that all vegetation subgroups were green, all urbanization subgroups were red, and all water subgroups were blue. Then, the changes were made permanent by combining all subgroups into one general class with the combine classes function. To asses the accuracy of the unsupervised classification, a confusion matrix was performed using 5 ground truth ROIs for each class. Based on the high accuracy of each image, the classified NDVI images were used in the change detection analysis.

Combined Classes of Unsupervised Classification on NDVI Images



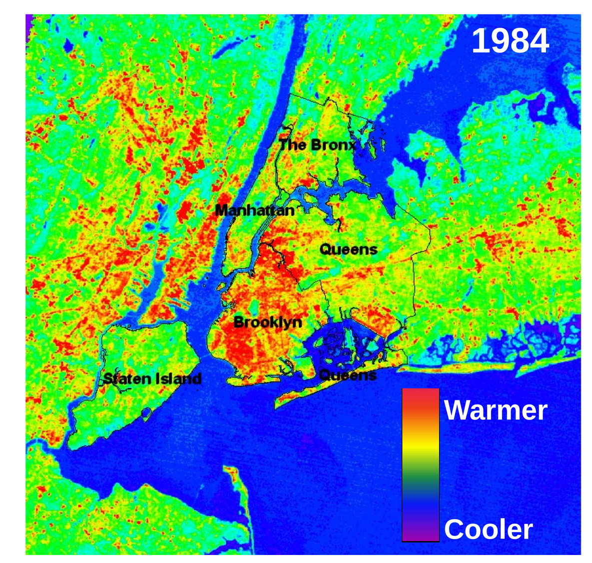
Red = Urban Green = Vegetation Blue = Water

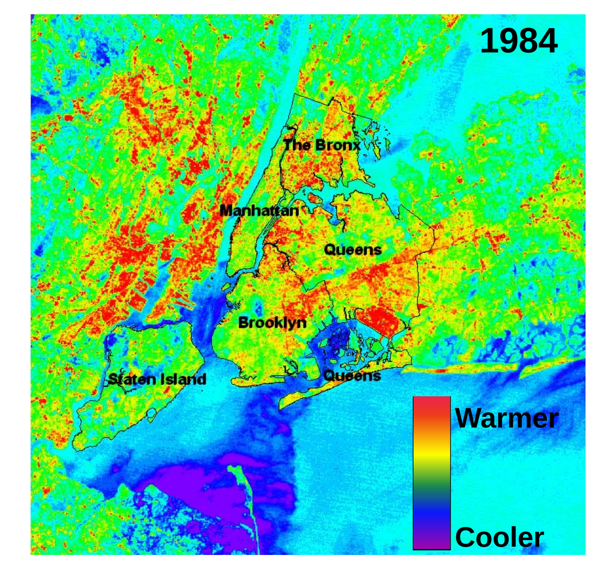
Change Detection for Urbanization, Vegetation, and Water

Performing a change detection compiled a detailed tabulation of changes between the two images. The resulting change detection bands showed where urbanization increased, where vegetation was lost, and where water was lost over the 15 year period in NYC. To do this, the change detection statistics operation was used, imputing the 1984 combined classes image first and the 1999 combined classes image second. A table of change detection statistics quantifying the changes in classes was produced as well as images indicating where each class changed and which new classes the original class turned into.

Visualizing Surface Temperature Data

In order to compare the differences in surface temperature in 1984 to 1999, the thermal band for each image was used. Since the images were taken by Landset 5 and Landset ETM+, band 6 was the thermal band used to display surface temperatures in NYC. The thermal images were clipped based off of the original Landset images in order to compare the combined classes images and the thermal images. Linking the colored thermal images to the combined classes images allowed for detection of the class with the warmest surface temperature. To be able to tell the difference between warmer and cooler areas, the images were changed to the "Rainbow" color scheme using the ENVI color tables operation. Warmer areas were red/yellow and cooler areas were blue/purple.

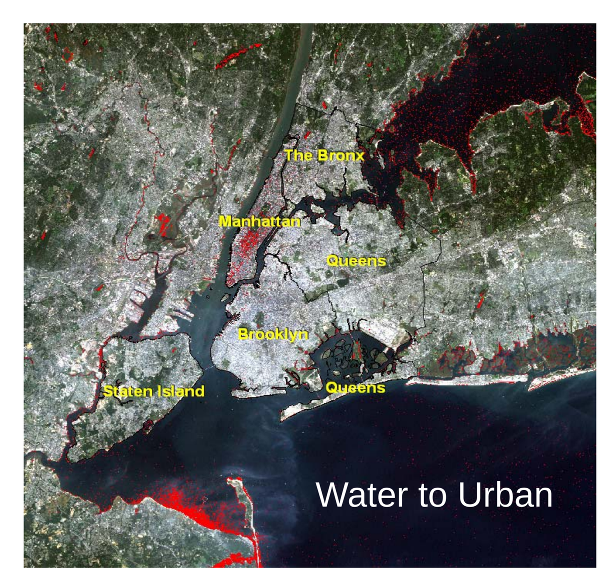


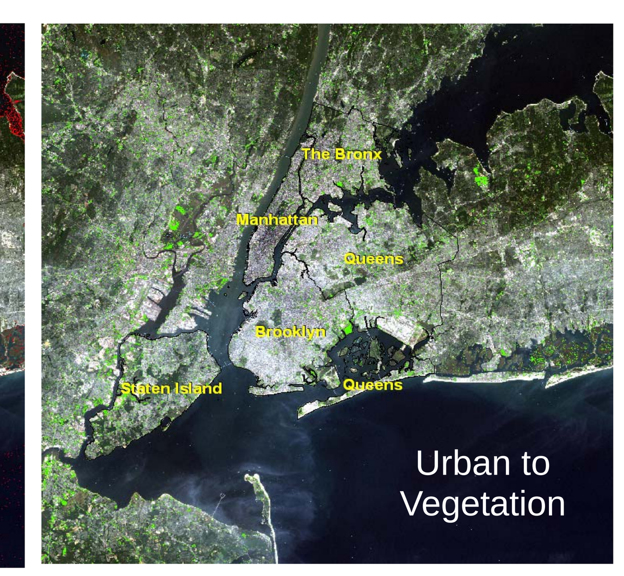


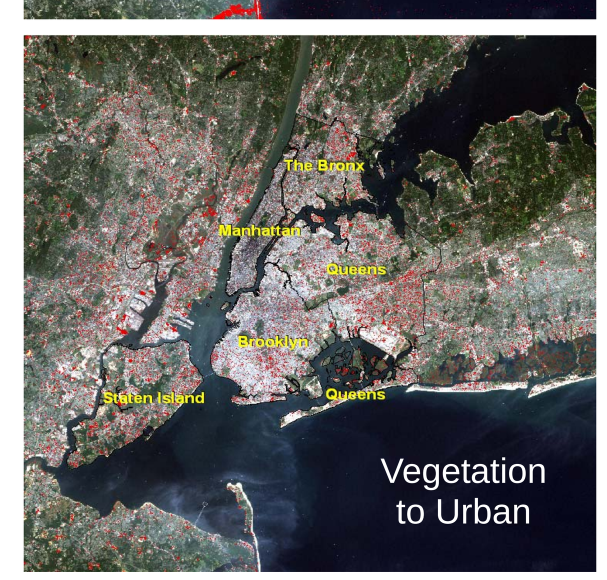
Results

Change Detection Analysis

Class	Pixel Change	Percent Change	Area Change (km^2)
Water	-100,752	-4.8%	-90.7
Urban	+113,693	+10.8%	102.3
Vegetation	-12,941	-0.5%	-11.7







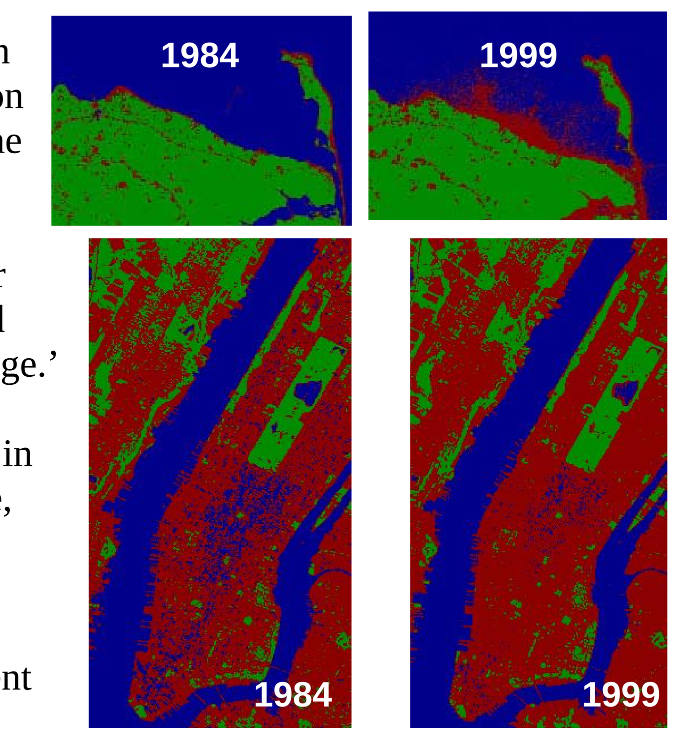
The results of the change detection analysis suggest that there was an overall trend of vegetation loss and urban area gain in New York City over the years 1984 to 1999. Both the water and vegetation classes experienced a loss in area with 90.7 km^2 and 11.7 km^2, respectively. At the same time, urban gained the most area with a 102.3 km^2 increase.

Unexpected Results

The results of the change detection analysis seem to imply that New York City experienced urban growth over the fifteen year period at the expense of vegetation in the area. However, if all vegetative areas were converted to urbanized areas, the change detection statistics should have shown vegetation loss to be around the same area as urban gain. In actuality, urban gain was substantially greater than vegetation loss by 90.6 km^2, which was equal to the water loss. Therefore, if all water change was error, the correct change in urbanization in NYC from 1984-1999 was 11.7 km^2. The small change in urbanization was unexpected, but NYC was already built up by 1984 and once a city is urbanized, growth tends to occur vertically rather than horizontally, which would not be detected by satellite images.

Error in Unsupervised Classification of Water

The change detection error for the water class occurred because of a cloud in the 1999 image that was misclassified as urban area and because of the shadow effect resulting from tall buildings in Manhatttan casting shadows on adjacent smaller buildings. The cloud was not present in the 1984 image, and thus represented a positive gain for the urban class when it should have been viewed as 'no change.' In addition, there were water misclassification errors in Manhattan. In the 1984 image, shadows from taller buildings caused urban areas to be classified as water. This error did not occur to the same extent in the 1999 image, and so this inaccuracy also added to the excessive urban gain.

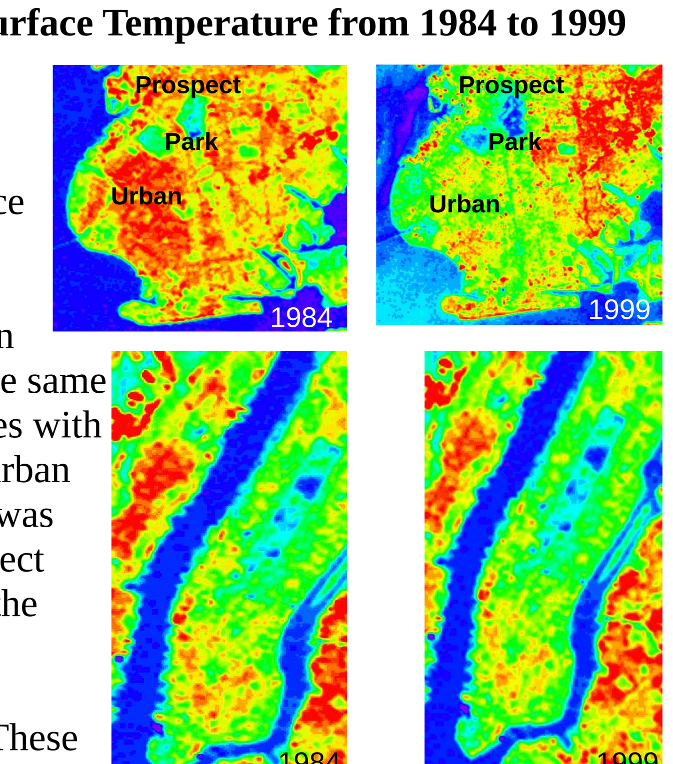


Surface Temperature Analysis

Displaying band 6 and comparing the location of colors to the combined classes images showed a general trend of vegetation being cooler than urban areas. Urbanized areas were found in the red/yellow part of the spectrum while vegetation came up as a cooler shade of blue/green. In a more general sense, the images showed warmer temperatures around the dense, urbanized areas of the city compared to the cooler, suburban and rural surrounding environments.

Error in Comparison of Surface Temperature from 1984 to 1999

The images could not be compared directly due to varying temperature patterns over the 15 years. Since surface temperatures were not determined, brightness could only be compared within each image. To see whether the same pattern occurred in both images with vegetation being cooler than urban areas, a close up of Brooklyn was analyzed. In both years, Prospect Park was a cooler shade than the surrounding urban area. The Manhattan shadow effect also occurred in the thermal data. These images showed that tall buildings actually have a cooling effect on surrounding buildings. Centralized red/yellow circles represent the tall skyscrapers and cooler shades like blue and green represent the adjacent smaller and shaded buildings.



Did the Urban Heat Island Effect Occur in NYC?

Since the heat island effect is defined by urban areas being warmer than surrounding suburban areas, NYC had already experienced the UHI effect in 1984, although the data does not tell the amount the effect increased by or if vegetation loss and urbanization had any impact on it.