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# Analysis of The Surface Radiative Budget Using ATLAS Data for San Juan, Puerto Rico

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**Abstract -- The additional heating of the air over the city is the result of the replacement of naturally vegetated surfaces with those composed of asphalt, concrete, rooftops and other man-made materials. The temperatures of these artificial surfaces can be 20 to 40 $^{0}$ C higher than vegetated surfaces. This produces a dome of elevated air temperatures 5 to 8 $^{0}$ C greater over the city, compared to the air temperatures over adjacent rural areas. Urban landscapes are a complex mixture of vegetated and nonvegetated surfaces. It is difficult to take enough temperature measurements over a large city area to characterize the complexity of urban radiant surface temperature variability. The NASA Airborne Thermal and Land Applications Sensor (ATLAS) operates in the visual and IR bands was used in February 2004 to collect data from San Juan, Puerto Rico with the main objective of investigating the Urban Heat Island (UHI) in tropical cities.**

**Keywords**: surface temperatures, airborne, ATLAS, urban heat island.

## 1. INTRODUCTION

The urban heat island is defined as a dome of high temperatures observed over urban centers as compared to the relatively low temperatures of the rural surroundings. These temperature contrasts are greater in clear and calm conditions, and tend to disappear in cloudy and windy weather by effects of thermal and mechanical mixture. Among the factors that cause the formation of a heat island is the replacement of natural vegetation with man-made materials which have a significant different energy and water balance. The partitioning of the sun's energy by these materials results in a change from mostly latent heat fluxes to sensible heat flux and into storage. This change leads to the great temperature differences observed during the early hours of the night when the energy stored during the daytime is released to the low atmosphere over the cities.

The case study of the urban heat island in a coastal tropical city was developed in San Juan, Puerto Rico. The analysis of the characteristics and patterns of this phenomenon was divided in two areas of study: the empirical analysis of observations, and the numerical analysis. The analysis of observations consists of gathering data of existing surface stations in the San Juan Metropolitan Area (SJMA) during last the 40 years and the deployment of new stations and sensors during the period of the ATLAS (Airborne Thermal and Land Applications Sensor) Mission campaign. We will be reporting on the results of the ATLAS mission.

## 2. METHODS

The ATLAS of NASA/Stennis operates in the visual and infrared bands. The ATLAS can detect 15 multispectral channels of the radiation through the visible, near infrared and thermal spectrums. The sensor also incorporates the active sources of calibration needed for all bands. The data is corrected for the atmospheric radiation, and georectified before the analysis of the data is performed. This ATLAS sensor has been used in other field campaigns to investigate the UHI in Atlanta, Salt Lake City, Baton Rouge, and Sacramento, all in the continental mass of the United States of North America (Luvall, et al. 2005).

The ATLAS Mission of San Juan, Puerto Rico was conducted during February of 2004 to investigate the impact of the urban growth and landscape in the climate of this tropical city. The flight plan of the mission covered the metropolitan area within San Juan, the national forest of El Yunque to the east of San Juan, the city of Mayagüez in the west coats of Puerto Rico, and the Arecibo Observatory located in the north-central coast, for a total of 25 flight lines. The downtown area of San Juan was covered in a horizontal resolution of 5 meters in flights during the day and during the night. The remaining areas of the city were covered in 10 meters of resolution. The flights were executed between the 11 and the 16 of February of 2004. In order to analyze the existence of an urban heat island in San Juan, and to support the data of the ATLAS sensor, several experimental campaigns for data collection were designed and conducted by different teams, in addition diverse numerical experiments were performed that helped to understand the phenomenon and its characteristics.

The atmospheric corrections needed to produce calibrated data sets from ATLAS involve an extremely complex procedure. They require direct measurements of the atmosphere extension coefficients by wavelength and profiles of atmospheric temperatures and water vapor. ATLAS instrument characteristics and calibration are also required. Figure 1 details the process flow followed for this project including resulted images from every relevant routine. A combination of software was used for the processing, including the public domain image processing/remote sensing package ELAS (Beverley and Penton, 1989; Graham, et al. 1986) and a series of

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custom programs. Two of the routines are Watts and Energy, which are the central processes to the overall processing flow.

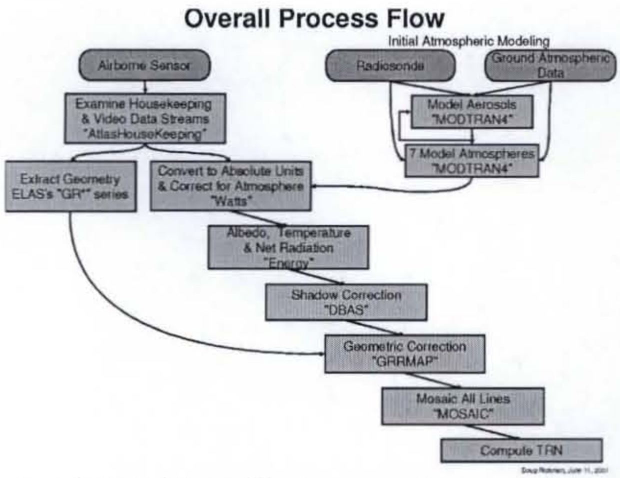



Figure 1. ATLAS data calibration process flow.

MODTRAN4 (Berk, et al. 1999) was used to model the atmospheric radiance and transmittance using input from radiosonde data and shadow band radiometers. Figure 2 details the procedure for calibrating the ATLAS sensor to produce the system transfer function to convert digital values (DV) into radiance measurements. Details about this procedure appear in Rickman, et al. 2000. These procedures produce ATLAS data files that are in physical units of energy. These files are used for the generation of files which derive albedo and surface temperature.

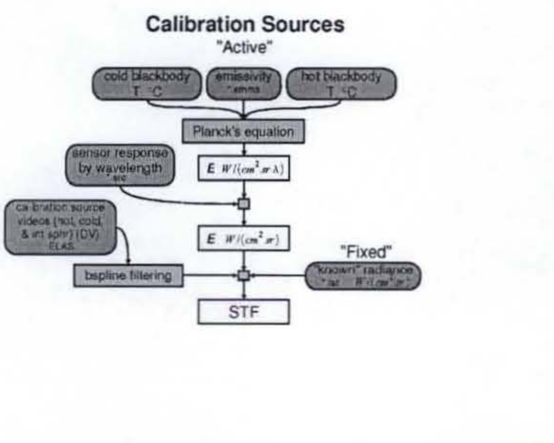



Figure 2. ATLAS System Transfer Function to calibrate data.

Surface temperature is a major component of the surface energy budget. Use of energy terms in modeling surface energy budgets allows the direct comparison of various land surfaces encountered in a landscape, from vegetated (forest and herbaceous) to non-vegetated (bare soil, roads, and buildings) (Oke, 1987). The partitioning of energy budget terms depends on the surface type. In natural landscapes, the partitioning is dependent on canopy biomass, leaf area index, aerodynamic roughness, and moisture status, all of which are influenced by the development stage of the ecosystem. In urban landscapes, coverage by man-made materials substantially alters the surface energy budget.

## 3. RESULTS

The San Juan metropolitan area is defined by the polygon illustrated in Figure 3. The calibrated and atmospheric corrected 10-meter mosaic surface albedo and temperature for the San Juan regional area is shown in figures 4 & 5. The images collected by the ATLAS were relatively cloud free, with only a few clouds in the southeast part of the image. The albedo ranged from a low of < 0.05 (water) to a high of 0.62 (clouds). The urban area had an albedo of about 0.16 to 0.18 and the tropical rain forest albedo of about 0.12 to 0.16. The surface temperatures ranged from the clouds around 10 °C to roof tops at over 62 °C . The vegetation temperatures ranged from 20 °C for the cloud forest to about 27 °C for the mangrove/swamp areas near the airport. If specifically examine the frequency distributions of albedo and temperature for San Juan urban area (figs 6 & 7) we see the complexity of the various surface types. The darker materials such as asphalt and rooftops typically have an albedo ranging form 0.05 to 0.18 and concrete from 0.10 to 0.35 (Oake, 1987). A few surfaces had higher albedos, which indicate either a white painted or a white membrane roof. The overall albedo for the urban areas was slightly higher than the non-urbanized areas due to the lack of vegetation and the common use of concrete in construction. However, surface temperatures for the urban areas were as much as 27 °C hotter that vegetated areas and exhibited more variability. If specifically examine the frequency distributions of albedo and temperature for San Juan urban area (figs 8 & 9) we see the complexity of the various surface types. The darker materials such as asphalt and rooftops typically have an albedo ranging form 0.05 to 0.18 and concrete from 0.10 to 0.35 (Oake, 1987). A few surfaces had higher albedos, which indicate either a white painted or a white membrane roof. The overall albedo for the urban areas was slightly higher than the non-urbanized areas due to the lack of vegetation and the common use of concrete in construction. However, surface temperatures for the urban areas were as much as 27 °C hotter that vegetated areas and exhibited more variability.

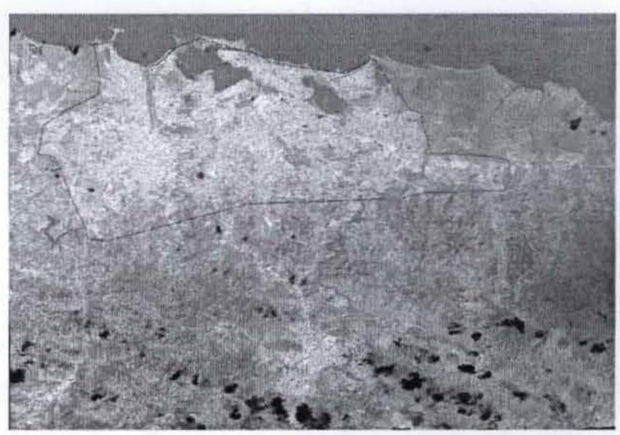


Figure 3 Polygon extracted of the San Juan urban area.

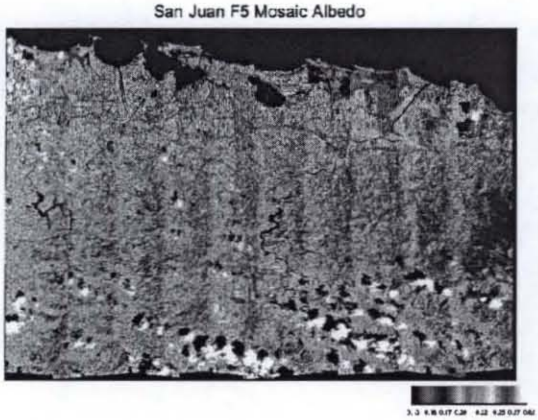



Figure 4. Flight 5 mosaic of albedo values covering the San Juan area.

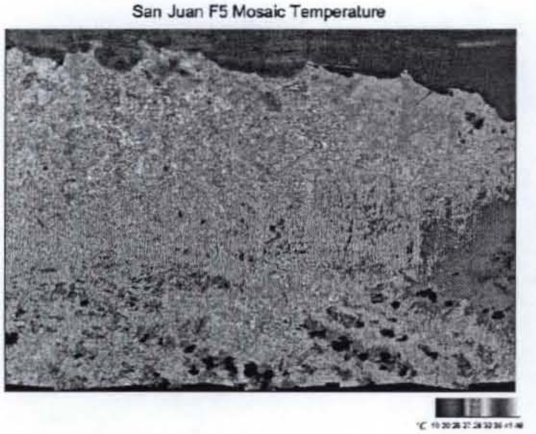
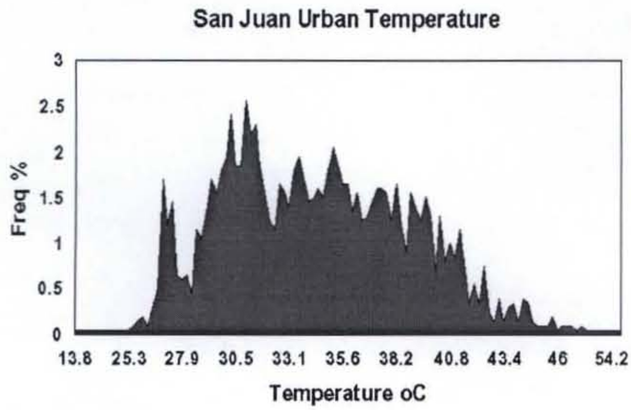



Figure 5 Flight 5 mosaic of temperature values covering the San Juan area.




.Figure 6. Frequency distribution of albedo for the San Juan urban area

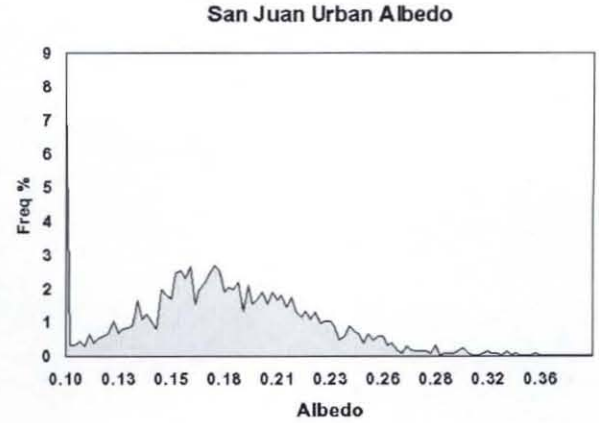



Figure 7. Frequency distribution of surface temperatures for the San Juan urban area.

## 4. CONCLUSIONS

The urban landscape represents a complex heterogeneous surface that strongly influences the development of the urban heat island. The urban landscape cannot be adequately classified using traditional structural based remote sensing classification techniques because these techniques are not directly related to the physical functioning of the surface energy budget. Calibrated and atmospherically corrected ATLAS data sets are required to quantify the surface energy budget. These data need to be incorporated into both meteorological and air quality models in order to assess the effectiveness of the heat island mitigation strategies. It is important to understand that albedo in of itself is not diagnostic for the determination of surface temperature. What is determinant is how a particular surface partitions the energy received from the sun. A vegetated surface has a relatively low albedo, but stays cool because the energy absorbed is used to evaporate water instead of heating the surface or conducted into storage as is typical of a man-made material.

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