2.1 MODIS LAND SURFACE RETRIEVAL IN SAN JUAN, PUERTO RICO DURING THE ATLAS FIELD CAMPAIGN

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ABSTRACT

The Airborne Thermal and Land Applications Sensor (ATLAS) from NASA/Stennis that operates in the visual and IR bands was used as the main sensor for a field campaign in San Juan, Puerto Rico with the main objective of investigating the Urban Heat Island (UHI) in tropical cities. The UHI represents the temperature difference between urban areas and surrounding vegetated areas and is a good indicator of the impact of the land use in the climate. The sensor was flown over Puerto Rico in a Lear 23 jet plane during February 2004. One of the efforts to support the data gathered by the ATLAS sensor was the acquisition of remote sensing observations for the flight period. A temporal analysis of this complementary data for the Atlas San Juan Mission is presented with the objectives of calibrating the response of satellite sensors such as MODIS (Moderate Resolution Imaging Spectroradiometer) to study the UHI effect in tropical and subtropical regions. An analysis of the surface temperature variation was performed using remote sensing images from MODIS for the same days of the ATLAS field campaign. Surface temperatures were estimated for San Juan using the land surface temperature product MOD11_L2 distributed by Land Process Distributed Active Archive Center (LP DAAC). These results show the maximum, minimum and averages temperatures in San Juan and in the rest of the Island of Puerto Rico as measured by MODIS. A comparison of temperatures between El Yunque rain forest and San Juan reflects a tendency of higher temperatures for the San Juan area, an indication of the presence of a UHI. The information retrieved from MODIS for land surface temperatures was compared with weather stations temperature measurements spread over San Juan reflecting similar temporal and spatial variations with absolute offsets of about 3.71°C due to the differences between surface and air temperatures. Observations from the weather stations and MODIS suggest an increase in temperature in urban areas during daytime over rural areas. One of the flight lines from the ATLAS sensor coincides with the pass of MODIS. Because ATLAS flight line spatial resolution is 10 meters and MODIS swath spatial resolution is 1 kilometer, an averaging of every 100 x 100 pixels in the ATLAS flight line was performed. Highest difference between ATLAS and MODIS was 12.33 °C where the ATLAS sensor had estimated 47.82°C for an area of 1 kilometer by 1 kilometer. This high difference is less than 1% of the errors between the two sensors. About 60% of the errors between surface temperatures is less than 4°C. Some differences between MODIS and other field sensors may be related to the total retrieval for Puerto Rico which in most cases was about 50%. Based on the available data from the MODIS product and the comparisons with other instrument measurements, some suggestions about calibrating the algorithm will be made for applications in tropical regions.

1. INTRODUCTION

Remote sensing measurements can provide land surface parameters such as temperature and albedo. These two parameters are the key elements in the study of urban heat island. A brief review of relevant works is provided in this section followed by a calibration exercise under the San Juan Atlas mission.

Landsat 7 has been used in urban heat island studies in the city of Atlanta [1]. This sensor has a spatial resolution of 60 m in the spectral range of 10.40 to 12.5 µm. One constraint of the instrument is the temporal variation due to overpasses through Puerto Rico which is every 16 days. Fukui [2] presented a study based on the surface temperature distribution and the urban structure in Tokyo using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and LIDAR data. ASTER has a spatial resolution of 90m in the spectral range of 8.125 to 8.825µm, 8.925 to 9.275µm and 10.25 to 11.65µm. In this study, two different scenes from ASTER were used to calculate the surface temperature. The correlation of the surface temperature and the urban structure shows the impact of green areas on the urban heat environment and the falling of surface temperature in tall buildings during daytime and increasing of surface temperature during nighttime. Furthermore, NOAA Advanced Very High Resolution Radiometer (AVHRR) thermal IR images have been studied to understand the urban microclimates of cities such as Paris and Los Angeles [3]. This radiometer has a spatial resolution of 1km and two thermal bands in the spectral range of 10.3 to 11.3µm and 11.5 to 12.5µm. MODIS has the same resolution as NOAA AVHRR but has the capability of acquiring data over 36 spectral bands. McCabe [4] compared MODIS and NOAA AVHRR land surface temperatures with ground based infrared thermometry measurements made in Tomago, Sandbeds, north of Newcastle, Australia. Comparisons show good

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agreement between MODIS, NOAA AVHRR and the infrared thermometer. No major research has been reported where remote sensing images are used to estimate surface temperatures in tropical and subtropical regions.

A calibration exercise was conducted for the MODIS sensor using information gathered during the San Juan Atlas mission with the intention of verifying the ability of this sensor in observing surface temperatures in tropical regions. The land surface temperature (LST) product from MODIS (MOD11 from level 2) has been developed to get LSTs at a resolution of 1km and was used for this study. The theoretical basis of the LST algorithm is described in Wan [5]. Some of the constraints of the MODIS LST product are discussed in Wan [6]. One important concern about the day/night algorithm is to apply it to tropical regions because of the less clear-sky days. The author concludes that the algorithm can be used globally even in tropical regions. This LST product has been used in the evaluation of forest fire risk at Northeast China. Guangmeng [7] suggests the use of LST for this type of fire studies.

During the ATLAS mission in San Juan, Puerto Rico, different images were collected and were analyzed to assess the accuracy of the MODIS sensor for tropical locations. Table 1 shows the date and time for every image collected from MODIS during the days of the San Juan ATLAS mission. MODIS acquired data from Puerto Rico twice a day. During day 047, MODIS passed at the same time the ATLAS airborne passed through San Juan. MODIS did not capture San Juan during the daytime of February 11, 2004 but it did capture the Island during the nighttime. The MODIS elapsed time during daytime may vary from one day to another.

Table1. Date and time for MODIS images

Date	Time
2004-02-11 (Day 042)	02:00 , 15:50
2004-02-12 (Day 043)	02:40 , 14:55
2004-02-13 (Day 044)	03:25 , 15:35
2004-02-14 (Day 045)	02:30 , 14:40
2004-02-15 (Day 046)	03:15 , 15:25
2004-02-16 (Day 047)	02:20 , 14:30

2. METHODOLOGY

MODIS land surface temperature images were georeferenced. The San Juan region was extracted according to the defined ATLAS GPS coordinates. Figure 1 shows the extracted San Juan region for the specified date and hour during daytime for the days of the ATLAS mission. One observation about the retrieval is the lack of identification of some pixels. The time period when most pixels were recovered was February 16, 2004 at daytime that the ATLAS overpassed San Juan at 10 meters resolution. The worst surface temperature retrieval was February 14, 2004 which corresponds to the cloudiest day of the ATLAS time period.

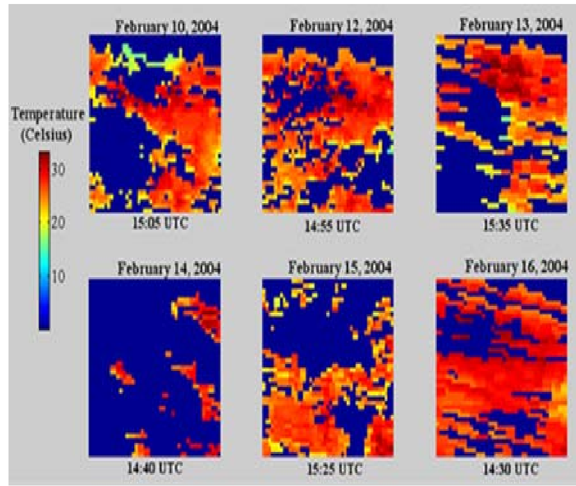


Figure 1: Extracted San Juan LSTs from MODIS during the ATLAS Mission period (Daytime).

The Airborne Thermal and Land Applications Sensor (ATLAS) operates in the visual and IR bands. It flies on a Lear 23 jet for flexibility and produces high resolution images of value to observe UHI. The mission also operated a 9 inch Zeiss camera for high resolution photographic work. Surface temperatures are calculated by using channel 11. Data processing was done at the Global Hydrology and Climate Center, MSFC/NASA under the direction of the Principle Investigator, Dr. Jeffrey C. Luvall. (jluvall@msfc.nasa.gov). Data are organized by city and then by aircraft data reference name. Files containing surface temperature have the extension ".energy". Files were created with the use of the ELAS software. Figure 2 shows a composite image that was taken in Hato Rey during the campaign. Retrieved surface temperatures from this flight path are shown in Fig. 3. Highest temperatures of about 60.2°C over building roof tops are observed.

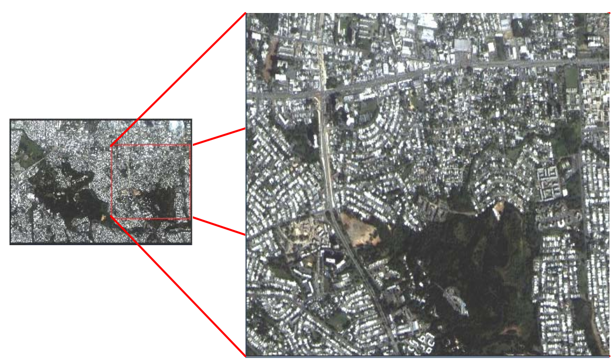


Figure 2: ATLAS RGB image from Flight 1 Line 23 Hato Rey, PR at 5 meters resolution.

Three different tasks were performed as part of the temporal analysis using MODIS. The first task was to calculate the maximum temperatures for San Juan and Puerto Rico during the time intervals mentioned before. To conduct this calculation, pixels that do not show retrieval were not taken into account. The second task was the comparison of MODIS surface temperatures with temperature sensors located in different places along San Juan. The third task was the cross-comparison of MODIS and the ATLAS sensor. One of the flight lines from the ATLAS sensor coincides with the pass of MODIS. Because ATLAS flight line spatial resolution is 10 meters and MODIS swath spatial resolution is 1 kilometer, an averaging of every 100 x 100 pixels in the ATLAS flight line was performed.

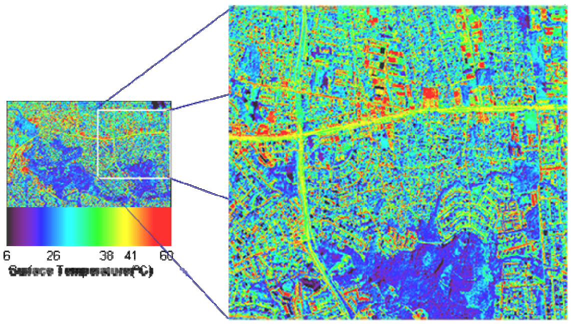


Figure 3: ATLAS surface temperature image from Flight 1 Line 23 Hato Rey, PR at 5 meters resolution.

3. RESULTS

Maximum temperatures from San Juan and Puerto Rico were observed from MODIS at 1km. Figure 4 shows the maximum temperatures for San Juan and Puerto Rico. The highest temperature observed was 37.87 ˚C during February 12, 2004 at 14:55 UTC and the lowest temperature was 22.29˚C during February 11, 2004 at 2:00 UTC.

A comparison of the available land surface temperatures from MODIS with surface temperatures from ground sensors located around San Juan during the ATLAS mission was also performed. The period observed occurred at 14:30 UTC in the same day of February 16, 2004. MODIS pattern seems to be more synchronized with the ground sensors for this case (see Figure 5). Differences in temperatures are reasonable because ground sensors were measuring air temperature and not land surface temperatures. At rural areas, surface temperatures tend to decrease while urban areas will experience higher temperatures.

Figure 4: Maximum surface temperatures for the ATLAS period

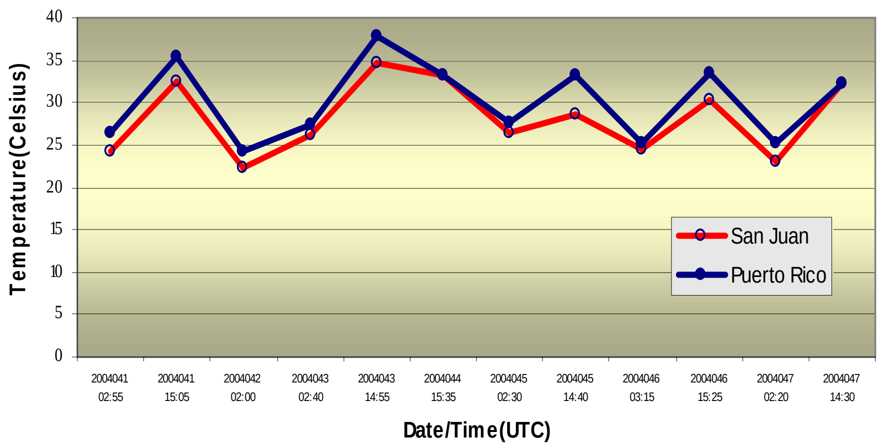
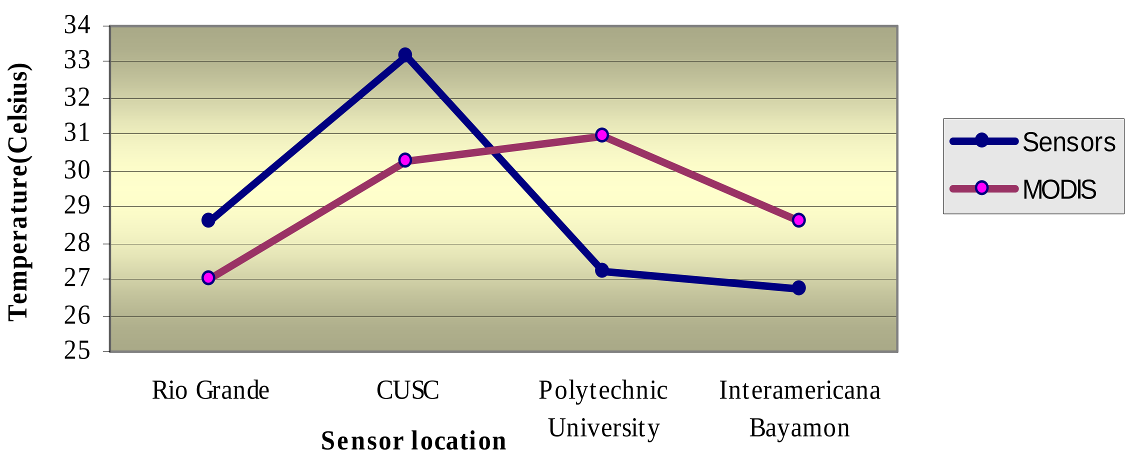


Figure 5: Temperature during 2004047 at 14:30 UTC



In Fig. 6(a) Flight 5 Line 14 appears in its visible channels and in Fig. 6(b) retrieved surface temperatures. A cross-comparison was performed between this flight line and MODIS (see Fig. 7). Highest difference between ATLAS and MODIS was 12.33 °C where the ATLAS sensor had estimated 47.82°C for an area of 1 kilometer by 1 kilometer (see Fig. 7). This high difference is less than 1% of the errors between the two sensors. About 60% of the errors between surface temperatures is less than 4°C. In three different areas MODIS and ATLAS retrieve equal temperatures (see Fig. 7).

(a) (b)

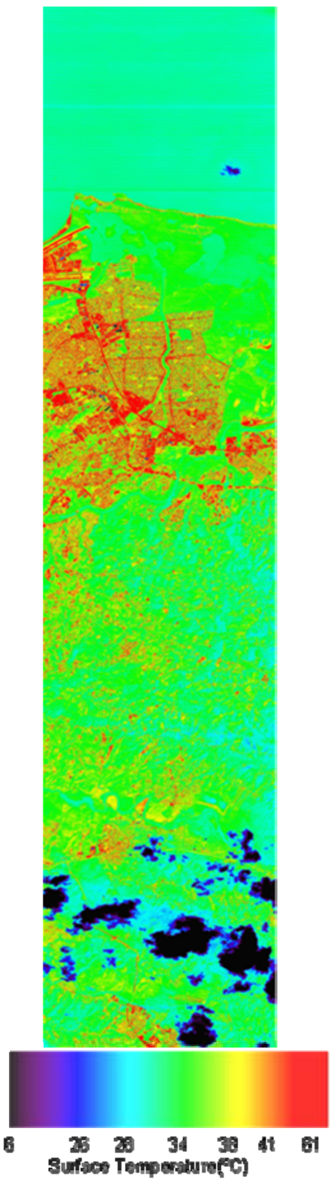


Figure 6(a): Visible image and 6(b): Surface Temperatures of Flight 5 Line 14 during February 16,2004 at 14:30 UTZ.

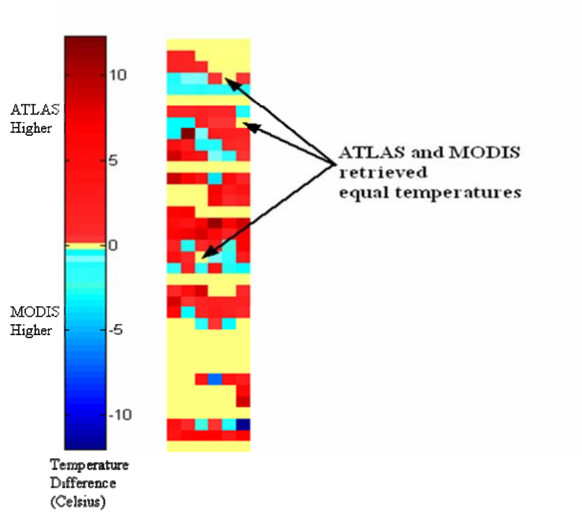


Figure 7: Cross-comparison between ATLAS flight line and MODIS.

The areas in which MODIS and ATLAS retrieve equal temperatures are dominated by ocean temperatures or vegetation temperatures. One important observation about the area in which the temperature difference is more than 10°C is the dominance of buildings and paved areas (see Figure 8(a)). Highest frequency of surface temperatures is observed in the range of 30's through 40's degrees Celsius (see Fig. 9).

(a) (b)

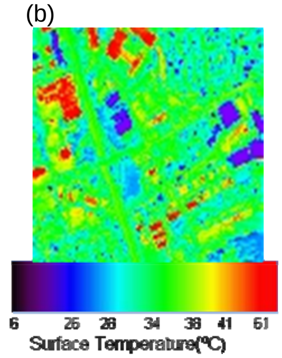


Figure 8(a): Visible image and 8(b): Surface Temperatures of urbanized area in Flight 5 Line 14.

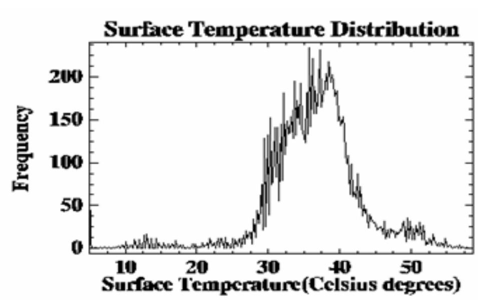


Figure 9: Histogram of surface temperature distribution from urbanized area.

4. CONCLUSIONS AND FUTURE WORK

Temperatures tend to rise at 14:00 to 15:00 UTC which is about 10:00 a.m. to 11:00 a.m. in Puerto Rico. Land Surface Temperature (LST) retrieval percent for MODIS reached about 50% in some cases. Cloud cover is one of the factors that may contribute to a low retrieval of LSTs from the MODIS sensor. Even if the retrieval rate is 50%, MODIS shows good agreement with the expected UHI pattern in San Juan. ATLAS surface temperatures indicate how serious the UHI effect in San Juan is by identifying higher temperatures of about 60°C. Similar retrieval of surface temperatures for MODIS and ATLAS occurred in ocean or vegetated areas.

Some of the tasks that are in process are the identification of specific locations in the georectified ATLAS images where ground stations were placed during the mission and comparisons with hobo sensors around El Yunque and San Juan. Based on the available data from the MODIS product and the comparisons with other instrument measurements, some suggestions about calibrating the algorithm will be made for applications in tropical regions.

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