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ANALYSIS OF UPPER AIR, GROUND AND REMOTE SENSING DATA FOR THE ATLAS FIELD CAMPAIGN IN SAN JUAN, PUERTO RICO

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Introduction

The general climate of the island of Puerto Rico is dominated by the easterly trade winds from the Atlantic Ocean, and during synoptically calm days by the topographic and local land surface characteristics [1]. The urban canopy of the metropolitan area of San Juan, capital city of the Island, may introduce a new microclimate that changes the characteristics of the low atmosphere and interacts with the other microclimates already present in the island. The primitive land cover and land use (LCLU) of the metropolitan area of San Juan was composed by broadleaf trees, moist soils, and very dense vegetation in general.

The urban LCLU changes the balance for the mass, momentum and energy between the bottom boundary and the lower atmosphere, creating different climate conditions over urban and rural regions. Some of these differences are low relative humidity and high temperatures observed in urban areas when compared to rural areas. These in turn produces a convective circulation over the urban areas, a phenomenon compared to the sea and land breezes, commonly known as heat islands (UHI). Factors that contribute to the formation of the UHI are anthropogenic heat sources, aerosols from pollutants, fast water canalization due to the presence of buildings and streets, among others. The comparison between urban and rural climates is the most common approach to analyze the UHI. These contrasts are larger in clear and calm conditions and tend to disappear in cloudy and windy weather. The UHI was recognized in the early 1950's as closed isotherms that separates the city from the general temperature field [2].

The impact of the urban LCLU in San Juan, Puerto Rico, was quantified calculating the difference between historical data sets for the air temperature over an identified urban area and a rural area dT(U-R). The analysis of the climatological data revealed that a UHI exists in the metropolitan area of San Juan, Puerto Rico. The data reveals a permanent urban heat island effect present in the SJMA during the year, which is increasing at a rate of 0.41°C/decade. These findings encouraged the planning and execution of an intense field campaign in February 2004 referred as the ATLAS San Juan mission. The focus of the remaining of this report is the analysis of the data for this field campaign.

Description of the Atlas Mission

The Airborne Thermal and Land Applications Sensor (ATLAS) from NASA/Stennis operates in the visual and IR bands. ATLAS is able to sense 15 multispectral radiation channels across the thermal - near infrared - visible spectrums and is capable of approximately 2.0 meter resolution per pixel when flown in NASA's Learjet. An ATLAS mission flight was conducted in San Juan, Puerto Rico during February 2004 to further investigate the impact of urban growth in the regional climate of this tropical city. The flight plan for the mission is shown in Figure 1 below. The central area of San Juan was covered at 5 meters resolution in day and night flights. The remaining areas were covered at 10 meters resolution. The flights were conducted between February 11th and February 16th. In order to analyze the existence of an urban heat island in San Juan, and to support the Atlas sensor data, several experimental campaigns for data collection were designed and conducted by different teams. The focus of the next sections is in the analysis of the supporting measurements during the San Juan ATLAS field campaign, specifically for upper air and ground weather stations.
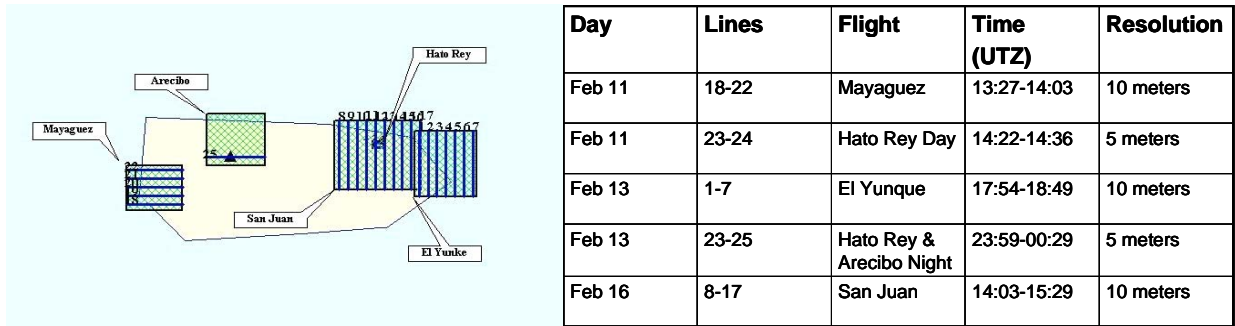
Day	Lines	Flight	Time (UTZ)	Resolution
Feb 11	18-22	Mayaguez	13:27-14:03	10 meters
Feb 11	23-24	Hato Rey Day	14:22-14:36	5 meters
Feb 13	1-7	El Yunque	17:54-18:49	10 meters
Feb 13	23-25	Hato Rey & Arecibo Night	23:59-00:29	5 meters
Feb 16	8-17	San Juan	14:03-15:29	10 meters

Figure 1: San Juan ATLAS Mission flight plan and execution

Upper Air Data

The upper air information consisted of sounding launches and synoptic information provided by the NCAR Reanalysis group. These data were complemented by a regional modeling exercise to verify consistency. The San Juan office of the National Weather Service (NWS) increased the frequency of the standard soundings during the mission days, and these were complemented by launches from Mayagüez in the west coast, San Juan, and Dorado, about 25 miles east of San Juan. A total of 29 soundings were launched during the mission.

The upper air data clearly shows that the atmosphere was unusually stable and dry during the days of the mission. February 11, for example, when lines 18-24 were collected, presented a highly stable and dry atmosphere as shown in Figure 2(a) below. The differences between the dew point and the temperature of the sound indicate a dry atmosphere. To evidence the dry conditions and stability of the atmosphere, NCAR reanalysis was used to verify the upper air synoptic conditions. This data set represents the most comprehensive combined upper air analysis at a resolution of 2.5 degrees [3]. The surface surface Lifted Index (LI) for 12 UTZ February 11, 2004 is shown in Figure 2(b) below. The LI is found by comparing the temperature of a parcel of air raised from the surface to the 500 mb level to that of the actual temperature at 500 mb. When the LI is the troposphere is unstable relative to surface based convection. Fortunately, a prevailing positive LI was present in the Caribbean region during the days of the mission. The exception for these conditions occurred in February 14th when low, cold clouds were present until late in the morning leading to local instability and precipitation in the San Juan area.

The density and frequency of the sounding launches provided the unique opportunity of observing the temporal and spatial variation of the atmospheric boundary layer across the Island of Puerto Rico. Combined sounding data for San Juan (SJ) and Mayagüez (MZ) are presented in Figure 2(a) below. It can be noted that the atmosphere is relatively humid at 00 UTZ and becomes dry as the local heating pushes upward the moist clouds leaving a drier lower atmosphere. It can also be noted that differences in the local boundary layers are present for San Juan and Mayagüez for levels below 900 mb only, may be due to the topography of Puerto Rico which presents peaks as high as 1,300 meters between the two locations. A comparison of the upper air data for San Juan(SJU) and Dorado (DOR), about 25 miles west of San Juan, reflects minimum differences in the lower thermal boundary layer for 00UTZ in February 14, 2004 and increasing humidity by 06 UTZ as shown in Figure 2(c). The differences in the thermal or mechanical boundary layers between these two points will be a direct effect of the urban landscape in San Juan. When the atmosphere is dry and stable, minimum differences are

observed, however, the humidity will increase faster in the rural area than in San Juan as the night progresses.
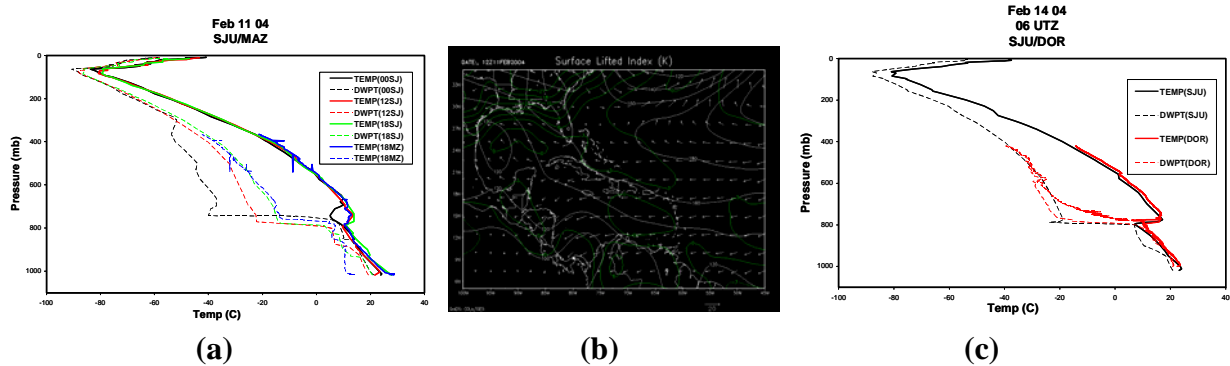

(a)   **(b)**   **(c)**

Figure 2: (a) Combined upper air data for San Juan(SJ) and Mayagüez(MZ), and (b) Surface lifted index for February 11
(c) Combined upper air data for San Juan(SJU) and Dorado(DOR) for February 14, 2004 for 00UTZ

Ground Stations Analysis

Weather stations and temperature sensors were placed at along lines following the prevailing northeasterly winds in order to analyze possible temperature differences between the commercial area, residential areas, and rural areas. The logging frequency of all the data loggers, stations and sensors alike, was set to 5 minutes. The UHI effect is defined as the dome of elevated air temperatures that presides over cities in contrast to their cooler rural surroundings. The weather station and temperature sensor data show some indications of an UHI in the metropolitan area of San Juan, P.R. and its surroundings as shown in Figure 3(a). It is clearly seen that the average noon temperatures during the time period of the Atlas Mission evidence the existence of a pronounced Urban Heat Island, with the peak of the high temperature dome exactly over the commercial area of downtown San Juan, represented by the stations in the Sagrado Corazón University and the UPR-Río Piedras Campus.

An analysis of the data gathered by the different stations shows that there were significant temperature differences between urban and rural areas during the Atlas mission. Peak true temperatures occurred at mid afternoon, and ranged from 33 to 35ºC in urban areas, and between 26-28ºC in sub-urban and rural areas. Low temperatures consistently reached 20-22 degrees in the late evening (around 10:00 pm). Maximum temperatures in rural areas were substantially lower than those in urban areas in the mid to late morning hours, more specifically between 9:00 am and noon with average temperature differences of 4.5ºC in such time frame, a temporal pattern not observed in previous Urban Heat Island studies of large continental cities, more notably the Atlanta, GA UHI measured by NASA in the early nineties [4]. It is also observed the nonappearance of a Cool Island, a dip of negative dT(U-R) opposite to the Heat Island caused by thermal heat storage. This might be due to the high density of low rising buildings in the metropolitan area of San Juan, despite having a large concrete density within the city. The high concrete density, and the importance of the soil moisture content and vegetation evapotranspiration in controlling the urban tropical climate, is evidenced by the variability of the UHI pattern with respect to rainfall. Even for relatively small and short precipitation events, in the order of only 8.4 mm during the entire mission, the temperatures in the commercial core of San Juan and the surrounding residential and rural areas become very similar, showing a low

dT(U-R). These results are summarized in Figure 3(b), which shows the true temperature, temperature difference, and accumulated surface precipitation for selected stations.

(a)   (b)
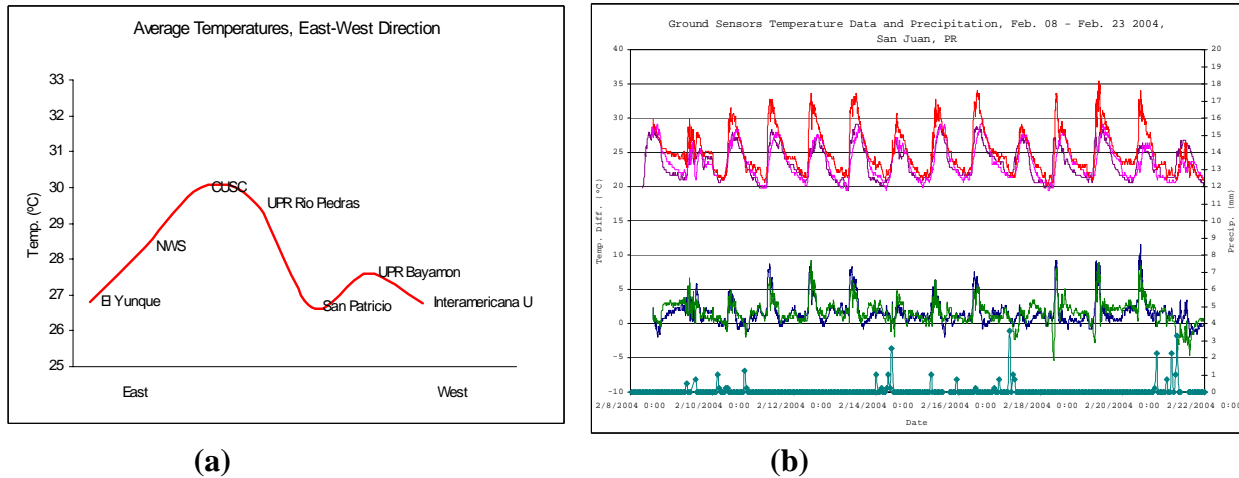
Figure 3(a) East-West cross-section of average noon temperature at selected locations in the San Juan Metropolitan Area and rural adjoining areas.

Figure 3(b). True temperature at a urban-commercial, urban-residential, and rural areas (top three series); temperature differences between the commercial area and the residential and rural areas (middle two series); precipitation total recorded every 5 minutes by the San Juan National Weather Service (bottom series).

Conclusions

- The upper air analysis for the days of the San Juan ATLAS Mission in San Juan, Puerto Rico, clearly shows that the lower and upper atmosphere of the Caribbean remained unusually dry and stable during the mission days, conditions favorably for UHI. A comparison of upper air data for San Juan, Mayagüez, and Dorado reflects that differences in the thermal boundary layers are due to the topography of the Island and to the differences between rural and urban landscapes.
- The weather station and temperature sensor data clearly show indications of the existence of an UHI in the metropolitan area of San Juan, P.R. Temperatures were on average 4.5ºC higher in the urban areas when compared to the observation of rural areas during the time period of 10:00 am to noon. The precipitation pattern and cloud coverage significantly affected the UHI of San Juan, PR.

References

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