P 2.7 TECHNIQUES TO ESTIMATE URBAN CANOPY PARAMETERS USING SATELLITE DATA

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1. INTRODUCTION

Many mesoscale meteorological and atmospheric transport and dispersion models (e.g., MM5, WRF, COAMPS, HOTMAC, RAMS) have undergone modifications recently to provide improved simulation capability in urban environments. One approach has been to introduce urban canopy parameterizations into the models to account for the urban terrain effects on drag, heat exchange, and turbulence production (Brown 2004). The implementation of urban canopy parameterizations has been accompanied by the need to provide urban canopy parameter (UCP) databases for the models to accurately represent the urban terrain characteristics in the models. UCP databases contain a range of terrain information such as building and tree height characteristics (e.g., mean, standard deviation, histograms), density characteristics (e.g., plan area fraction, sky view factor), drag factors (e.g., frontal area index), energy trapping characteristics (e.g., sky view factor), and aerodynamic roughness parameters (e.g., roughness length, displacement height). Creating UCP databases has two major constraints – the need for fairly high spatial resolution (250-m to 1-km grid cell size) and coverage of a regional scale (thousands of square kilometers). Early approaches to represent urban areas in models relied on adjusting parameter values in look-up tables corresponding to land use / land cover (LULC) categories. Additional modification of models produced new land surface schemes operating with gridded UCP databases some entirely eliminating the need for land use look-up tables. Methods to derive the gridded UCP databases that emerged in response to the model developments included image processing of digital terrain models and geographic information system (GIS) analysis of three-dimensional digital building polygons (Burian et al. 2006). With the image processing and GIS approaches, data management and processing issues limited application of the techniques to relatively small areas where digital terrain data had been collected. A globally-applicable method to develop UCP databases at a regional or larger scale with a rapid turnaround time from data acquisition to UCP database creation have not been developed and tested. This paper reports on the preliminary assessment of techniques to derive UCPs using satellite data with the goal of reducing UCP database development time and effort.

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2. METHODS

This paper describes the preliminary evaluation of satellite-based approaches to derive UCP databases. Three new methods are described – the use of Synthetic Aperture Radar (SAR), Shuttle Radar Topography Mission (SRTM), and high resolution multispectral data. The concepts are introduced and preliminary results are presented and discussed.

2.1 *Study Area*

The study area chosen for this paper is the Houston metropolitan area (centered at 29°40' N and 95°18' W). Houston was selected for this study because the authors had access to a unique morphological database consisting of airborne LiDAR-based digital terrain model (1-m resolution) and three-dimensional building database covering more than 1600 km^2. In addition, the metropolitan area covers a large area and has a diverse mixture of development types and morphological properties to fully test new ways to characterize urban morphology. A subset of the Houston metropolitan area covering around 210 km^2 was chosen for the preliminary testing. The analysis extent for this study was carefully chosen to include the tall building district (TBD) and surrounding high- and low-intensity residential areas.

2.2 *Data Types*

In this paper, a variety of data sources were explored to derive the test set of UCPs (Table 1). The preliminary set of satellite data selected was chosen to include both radar and spectral data sources. Figure 1 illustrates the comparison of the data types for the Houston TBD.

Table 1. Satellite data sources.

Data Type	Date of Acquisition	Source
Synthetic Aperture Radar (SIR-C)	Apr 1994	USGS
Laser Altimetry	Nov 2001	Terrapoint
Multispectral (Landsat)	Not specified	USGS
InSAR (SRTM)	Feb 2000	USGS

2.2.1 Synthetic Aperture Radar

The objective of the first phase of the research was to develop a technique to estimate UCPs from SAR backscatter. The hypothesis behind developing this technique is that the magnitude of the SAR backscatter depends on the arrangement and density of urban roughness elements (target elements) and the target height. The approach used in this paper is to use the SAR backscatter data in conjunction with gridded UCPs computed using high resolution LiDAR data and develop regression relationships between the SAR backscatter and the UCPs.

The first step, involved computation of UCPs from LiDAR data. The height raster dataset was determined by subtracting a 1-m bare-earth digital terrain model (DTM) from a 1-m full-feature non-ground raster dataset. The height dataset was processed using the Urban Morphological Analysis Processor (Burian et al. 2005) to compute the UCPs at two different resolutions: 250-m and 1-km. The results presented in this paper are specific to 1-km resolution (Fig. 1).

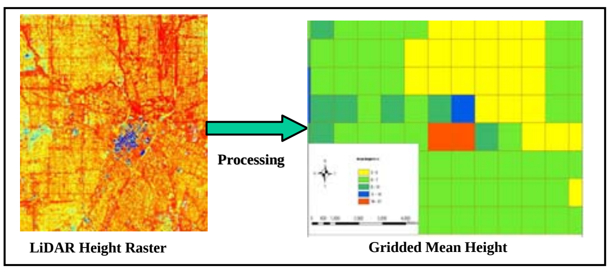

Fig. 1. Derivation of UCPs from LiDAR.

The SIR-C data was synthesized in ENVI 4.2. The SAR image consisted of radar backscatter values ranging from 0 to - 300 dB. Rapid inspection indicated rougher surfaces (downtown Houston) had backscatter coefficients in the -5 to -10 db range and those for very smooth surfaces had backscatter coefficients from - 35 to - 300 dB. To overlay the SAR image with the LiDAR derived heights, plan area fraction, frontal area index, and roughness lengths rectification to the proper scale and projection was required. Georeferencing was performed in ArcGIS using nine ground control points selected from the road network line feature dataset verified with a high-resolution aerial image. The SIR-C image was intersected with the gridded UCPs and various SAR metrics were calculated for each grid cell: mean, range, and standard deviation. The mean backscatter measure was selected as the value to report in this paper because it provided the best results in this preliminary analysis.

The first set of tests involved analyzing the relationship between the mean SAR backscatter in a grid cell and various UCPs representing height (mean height), density (plan area fraction), drag (frontal area index, roughness length), radiation trapping (sky view factor) characteristics of the urban fabric.

2.2.2 *Shuttle Radar Topography Mission*

The Shuttle Radar Topography Mission (SRTM) provides global coverage of digital elevation datasets in two different resolutions: 1-arc second (30-m) and 3-arc second (90-m). SRTM data has been used for a wide range of topographical analyses, some in urban environments. We have attempted to use the SRTM data to compute gridded UCPs. The 1-arc second (30-m) finished SRTM data was obtained from USGS. A raster of roughness element heights was created by subtracting the USGS 30-m DEM from the SRTM full-feature DEM. The height raster was then processed to compute a set of test UCPs for the Houston metropolitan area: mean height, plan area fraction, frontal area index and roughness length on 1-km grid resolution. The UCPs produced from SRTM were compared to the UCPs obtained from LiDAR (considered to be the “true” observations to test the model).

2.2.3 Multispectral Data

A preliminary analysis to relate the reflectance values from multispectral data to UCPs was performed. For this paper, Landsat data was used. Following the same approach as SIR-C data, the multispectral data was intersected with computed UCPs to see how they related. The standard deviation of spectral reflectance (from Landsat) was the first measure compared to UCP values.

Fig. 1 illustrates a comparison of the LiDAR, SAR, and SRTM datasets against the building dataset. The higher resolution of the building data and the LiDAR raster is clearly shown, with the SRTM data having the coarsest resolution. The resolution and other characteristics explain some of the observations from the analysis presented in the next section.

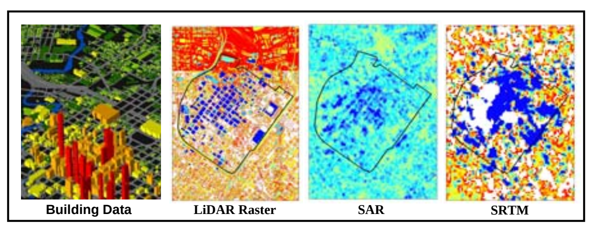

Fig. 2. Building data, LiDAR data and SIR-C data, SRTM data in TBD Houston. Blue color cells in LiDAR and SRTM indicate taller buildings and in SAR image, blue color cells indicate rougher surfaces (taller buildings)

3. RESULTS

3.1 *SAR*

The scatter plots of mean height, plan area fraction, and frontal area index versus mean SAR backscatter coefficient are shown below (Figs. 3, 4, and 5) for the 220 grid cells in the Houston study area. The scatter plots show a weak relationship between SAR backscatter and mean height, plan area fraction, and frontal area index relate to backscatter but not significantly (R square value of 0.1). We do see general trends that area consistent with expectations - mean height increases as the mean backscatter magnitude increases. But there is significant scatter in the data preventing the development of a useable functional fit.

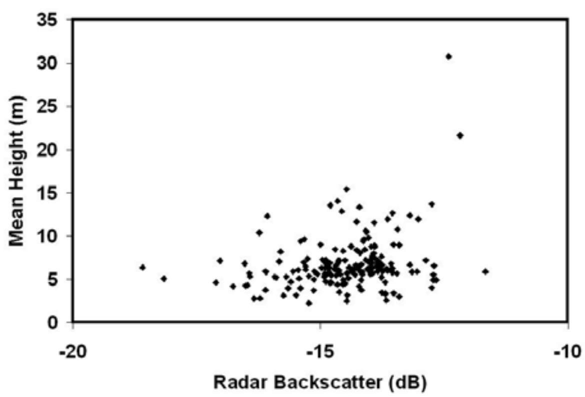

Fig. 3. Radar backscatter versus mean height.

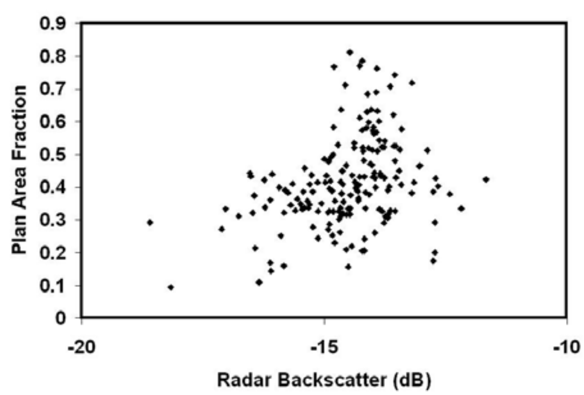

Fig. 4. Radar backscatter versus plan area fraction.

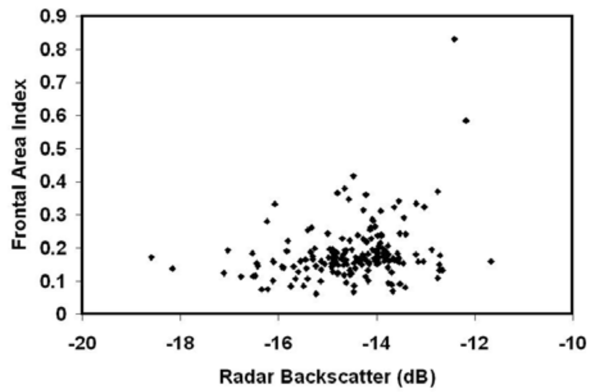

Fig. 5. Radar backscatter versus frontal area index.

As a next step, the mean backscatter was related to the roughness length which incorporates mean height, plan area fraction and frontal area index in its computation (when using morphometric relationships). For the model development 85% of the cells were used and the developed model was tested on the remaining 15% cells. Initially, the model developed had an R Square value of 0.4. The data did exhibit the expected relationship between mean backscatter and roughness length: as the roughness length increases, the backscatter increases. Yet the data displayed several outliers that needed to be investigated. Manual inspection of the values of the grid cells and aerial photos indicated poor data and limitations of the SAR to represent certain UCP values. For instance, in some cases clear data errors were present in the computation of the roughness length caused by the original data source used to produce the UCP gridded dataset. In those instances where clear data errors were a problem the grid cells were removed from subsequent analyses (including revisions of previous work). Another problem noted was the higher plan area fraction grid cells (those covered or nearly covered by buildings and trees) would have rather low roughness lengths (because their displacement heights were correspondingly higher). However the cells would have high backscatter because of the roughness present. These cells were also removed because of the disconnect between the morphometric equations used to compute the roughness length and the roughness measured by the backscatter. Hence, the models developed have limitations for application in areas with a set range of density (plan area fraction less than 0.5 is usually a cutoff chosen). The model developed after removing the outliers exhibited a fairly good fit to the data, with an R square value of 0.78 (Fig. 6). The developed model was tested on the 15% remaining cells and good performance was noted. In general the modeled values match the values produced by the morphometric calculations fairly well (Fig. 7).

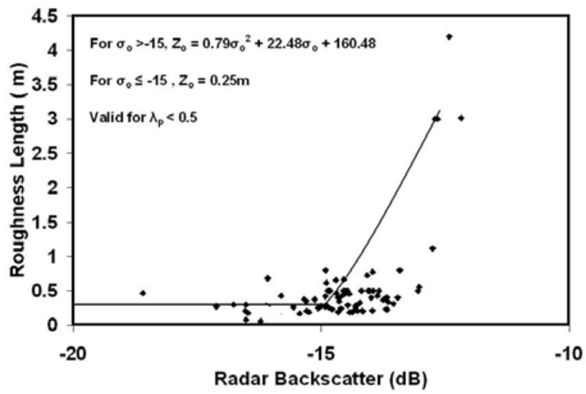

Fig. 6. Model developed for roughness length (Macdonald, Incident wind angle 0^o)

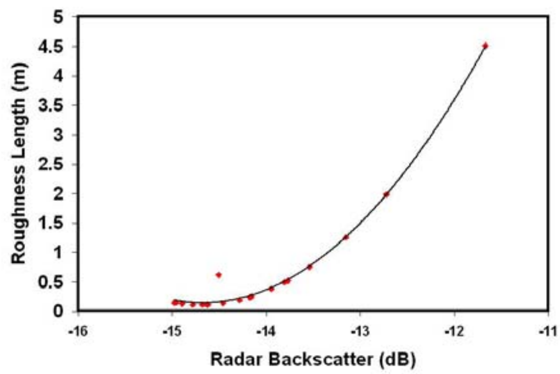

Fig. 7. Model tested results for roughness length (Macdonald, Incident wind angle 0^o)

3.2 *SRTM*

A comparison of the SRTM computed mean heights with the LiDAR computed mean heights is shown in Fig. 8. SRTM data seemed to capture the parameters mean height and frontal area index (not shown) quiet well but not the plan area fraction (not shown). Our preliminary results suggest the use of SRTM for computing UCPs is an efficient technique to generate UCPs globally compared with the time consuming process of collecting and analyzing LiDAR data for large areas. Further exploration is therefore warranted.

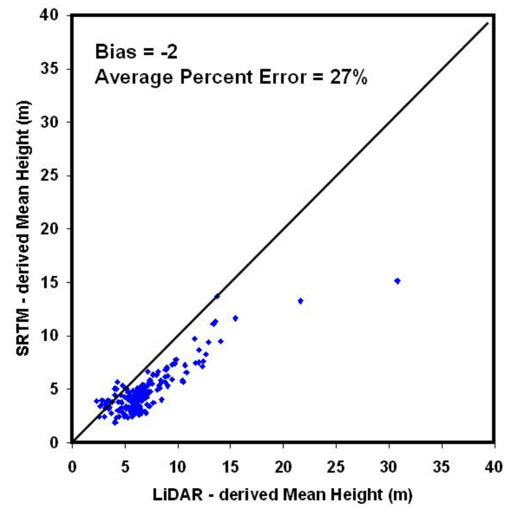

Fig. 8. Comparison of LiDAR and SRTM mean heights

3.3 *Multispectral Data*

The standard deviation of the spectral reflectance (from Landsat) was the first measure of multispectral data compared to UCP values (Fig. 9). The preliminary results indicate the potential for a model to be developed, but more work is needed to refine the fit.

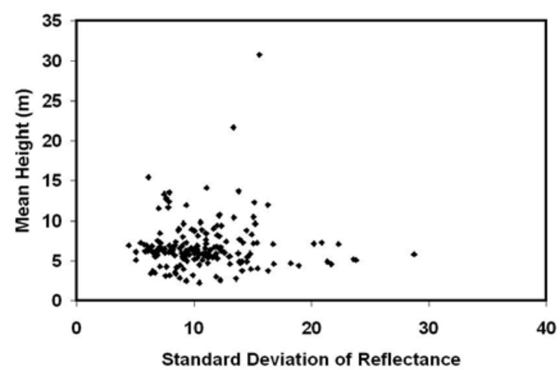

Fig. 9. Mean height versus reflectance.

4. SUMMARY

In this paper, methods to rapidly derive UCPs for large areas from satellite data were introduced. Our preliminary results lead to the conclusion that many of the satellite datasets such as SIR-C, LiDAR, SRTM and Landsat have a great potential for estimating UCPs. Also, our results suggest that using a combination of the data sources to develop a multivariate model will have a greater potential for estimating UCPs. For instance, SIR-C data captures the roughness characteristics well and likewise SRTM and LiDAR are suitable for other UCPs. Table 2 summarizes our preliminary recommendations for data sources.

Table 2. Suitability of various satellite datasets.

Satellite Data	Best suited for UCPs
SIR-C	Mean Height, Roughness Length
LiDAR	Mean Height, Plan Area Fraction , Frontal Area Index
SRTM	Mean Height, Frontal Area Index, Raupach Roughness Length

Future work involves exploring the combinations of satellite datasets, refining the relationships presented in this paper, and extending the model testing to multiple cities.

5. REFERENCES

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