# COMPARISON OF NDTI METHODOLOGIES TO CLASSIFY INFRASTRUCTURE IN AN URBAN BATTLESPACE FROM THERMAL IR SIGNATURES

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## ABSTRACT

A major challenge of remote infrastructure classification is to distinguish pavements from roofs. We proposed that, due to their differing thermal masses, these elements will heat and cool differently. Therefore, their thermal infrared (IR) signatures will differ throughout a 24-hour cycle. We propose a method to rapidly identify urban infrastructure that will assist the Future Force in dominating the urban battlespace to the same degree that the current force dominates open terrain. The Future Force needs tools that use automated prediction, pattern recognition, and reasoning decision support to understand the battlespace environment in a collaborative network-centric environment. Infrastructure classification that makes use of hyperspectral IR data from remote sensors helps to fill this need.

We developed a fundamental thermal heating model for these infrastructure elements, and tested the model on spectral data gathered by NASA's Advanced Thermal and Land Applications Sensor (ATLAS) instrument. ATLAS is a 15-channel multispectral scanner that includes both the standard visible and near-IR bands, and adds additional bands in the middle reflective infrared and thermal infrared range (TIR). The TIR capability permits the accurate measurement of thermal response for different land characteristics. Image processing techniques were applied to the imagery, focusing on the thermal bands (1015). A new indicator was proposed and tested in this research, the Normalized Difference Thermal Index (NDTI). Development and verification of the thermal model was described in a paper presented at the 25th Army Science Conference (McInerney et. al., 2006). In presenting this subsequent paper, we will detail the development of the NDTI, and provide more examples.

The NDTI is based on the premise that materials have different spectral responses, so that ratioing the significantly distinguishing bands will provide a sensitive and comparable test of thermal character.

The NDTI was calculated for each of the 180 unique combinations of thermal bands. In analyzing the results, the desire was to have the roofs and pavements appear distinctly separate. Statistical analysis of the NDTI technique was conducted to find the range, mean, and standard deviation of cells that were of either the pavement or roof type.

This research finds that the NDTI, (based on bands 13 and 14, and bands 13 and 15), provides the best tradeoff between correctly identifying pavement and roofs, and distinguishing between them. NDTIs from these bands produce well-defined images that accurately identify ground-truth points, as shown in the image of downtown Atlanta.

## 1. INTRODUCTION

### 1.1 Background

Remote sensing is the collection of data and information about an object from a distance. The evolution of sensor technology allows greater feature delineation, due to increased spatial and spectral resolution. The increased spatial resolution is crucial for distinguishing between buildings and other characteristics of the urban landscape.

The increase in sensor spectral resolutions has encouraged materials identification. Many materials have a distinctive spectrum in the hyperspectral region. However, even when using the most advanced hyperspectral remote sensing techniques, it still is not possible to distinguish clearly between pavements and roofs (Herold, 2004). Their hyperspectral signatures are similar, because they are made from similar materials. We hypothesized that the thermal emissions of pavements and roofs would vary throughout the day,

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| **01 DEC 2008** | **N/A** | **-** |

4. TITLE AND SUBTITLE
**Comparison Of Ndti Methodologies To Classify Infrastructure In An Urban Battlespace From Thermal Ir Signatures**

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
**U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory Champaign, Illinois, 61822**

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release, distribution unlimited**

13. SUPPLEMENTARY NOTES
**See also ADM002187. Proceedings of the Army Science Conference (26th) Held in Orlando, Florida on 1-4 December 2008, The original document contains color images.**

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | |
| **unclassified** | **unclassified** | **unclassified** | **UU** | **8** | |

due to differing construction techniques and thermal masses.

In our study, we used data taken by the ATLAS sensor system onboard a NASA Stennis LearJet over an area centered on Atlanta, Georgia, in May 1997 (Quattrochi, 2000). Data was collected approximately 5,032 meters above mean terrain, resulting in a spatial resolution of approximately 10m per pixel. Spectral bands 17 are similar to those on the Landsat Thematic Mapper (TM) satellite.

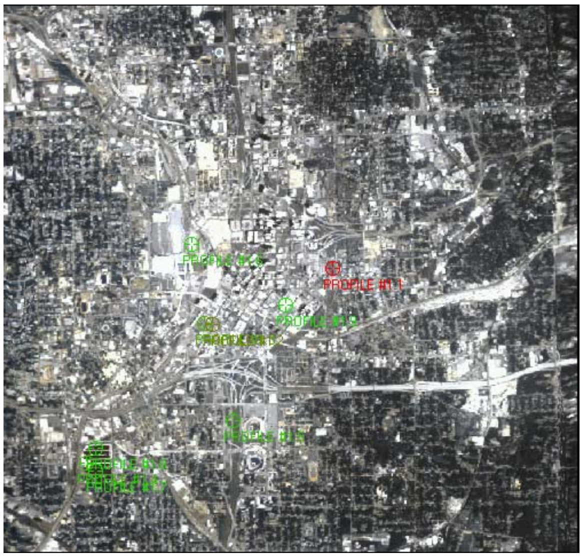

Figure 1. Visible image of downtown Atlanta with initial test locations.

Various image processing techniques were applied to the ATLAS imagery, emphasizing the thermal bands (bands 1015). There were 16 ground-truth points that were identified as either roofs or pavements. These points were used to determine the accuracy of the different analysis techniques.

### 1.2 Objective

The research objective was to apply the NDTI technique to the ATLAS' visible, near-infrared, and thermal-infrared bands, and to propose the most advantageous combination of bands for differentiating roofs from pavements.

### 1.3 Approach

The Normalized Difference Thermal Index (NDTI) was calculated for each of the 180 unique combinations of thermal bands. In analyzing the results, the desire was to have the roofs and pavements appear distinctly separate. Statistical analysis of the NDTI technique was conducted to find the range, mean, and standard deviation of cells that were of either the pavement type or roof type.

To objectively evaluate how well each of the NDTIs performed in distinguishing pavements versus roofs, the following procedure was followed:

- Mask out all cells for each NDTI to be evaluated, except those that are of the cover type under consideration (i.e., either pavement or roof, based on our ground control points).
- Apply an algorithm developed within our Geographical Information System (GIS) to consider only NDTIs that exist at our ground control points.
- Find the range, the mean, and the standard deviation from cells of a given cover type (either pavement or roof).

This procedure generated the statistics needed to evaluate the quality of the various NDTIs. The criteria for a desirable NDTI are:

- For the same band ratio, the mean values should be as widely separated as possible
- For each cover type, the peak should be well defined (i.e., the standard deviation should be small).
- For each cover type, there should be only one well-defined peak.

## 2. NORMALIZED DIFFERENCE THERMAL INDEX ANALYSIS

### 2.1 The NDTI

A commonly used remote sensing technique is to divide the values of a sensor's different spectral bands (at the same location) by each other. A small ratio implies small change, and a large ratio means there is a greater spectral difference. This technique is used for many applications, such as sensing minerals in earth ores. However, for more sensitive comparisons, a more sophisticated technique is shown in Equation 1:

$$\frac{\text{Band}(x) - \text{Band}(y)}{\text{Band}(x) + \text{Band}(y)} \qquad (1)$$

This process is called a "normalized index" and results in values ranging from -1 to +1. The normalization allows for comparison between different bands. The procedure was developed to aid in identifying vegetation, by using the large difference in the absorption of the red and near infrared bands.

### 2.2 The Advanced Thermal and Land Applications Sensor

The Advanced Thermal and Land Applications Sensor (ATLAS) data was used for the purpose of distinguishing between pavements and roofs. ATLAS sensor channel assignments are listed in Table 1. Data was collected at approximately 5,032 meters above mean terrain resulting in a spatial resolution of approximately 10m. ATLAS data was acquired for an area centered on Atlanta. A small section of the available data was cut out (Figure 1) to provide a manageable amount of data to process and store.

### 2.3 Statistical Results

An examination of the resulting statistics for all combinations show that bands 7 and 8 regularly appear in the top choices for correctly identifying roofs and pavements. For pavements, the top 10 combination performers are presented in Table 2; bands 8 and 7 clearly dominate. The top roof combination performers also are presented in Table 2. Once again, bands 8 and 7 dominate and although not in the same order, the same companion bands are present. It is interesting to note that if one simply wants to identify these materials, the existing band 7 of the Landsat TM also will do the job well.

Although bands 8 and 7 are excellent at identifying pavements and roofs, identification by itself is not sufficient. In addition to simply correctly identifying these covers, we must be able to separate roofs and pavements from each other. Thus, it would be beneficial if the best identification of roofs and pavements, respectively, also provided the best distinction between them. As Figure 2 shows, such is not the case. So, it is necessary to trade off some ability to identify roofs and pavements correctly for an ability to distinguish between them. To do this, we must find combinations where the difference between the roof pavement means is as great as possible.

Table 1. ATLAS channel specifications.

| | Channel | Band limits (μm) |
|---|---|---|
| Visible Bands | 1 | 0.45 – 0.52 |
| | 2 | 0.52 – 0.60 |
| | 3 | 0.60 – 0.63 |
| | 4 | 0.63 – 0.69 |
| Near Infrared (NIR) Bands | 5 | 0.69 – 0.76 |
| | 6 | 0.76 – 0.90 |
| | 7 | 1.55 – 1.75 |
| | 8 | 2.08 – 2.35 |
| Thermal Infrared (TIR) Bands | 9 | 3.35 – 4.20 |
| | 10 | 8.20 – 8.60 |
| | 11 | 8.60 – 9.00 |
| | 12 | 9.00 – 9.40 |
| | 13 | 9.60 – 10.2 |
| | 14 | 10.2 – 11.2 |
| | 15 | 11.2 – 12.2 |

Table 2. Best ATLAS band combinations to identify pavements (left) and roofs (right).

| **Pavements** | | | | **Roofs** | | |
|---|---|---|---|---|---|---|
| **Bands** | **Mean** | **Standard Deviation** | | **Bands** | **Mean** | **Standard Deviation** |
| b3_b8 | 0.926165 | 0.009391 | | b6_b8 | 0.908232 | 0.016011 |
| b1_b8 | 0.940455 | 0.009864 | | b1_b8 | 0.928867 | 0.018773 |
| b2_b8 | 0.923891 | 0.010815 | | b3_b8 | 0.917677 | 0.018994 |
| b4_b8 | 0.903840 | 0.012245 | | b2_b8 | 0.911280 | 0.021258 |
| b5_b8 | 0.917798 | 0.014802 | | b5_b8 | 0.903334 | 0.020968 |
| b6_b8 | 0.923959 | 0.017123 | | b4_b8 | 0.895039 | 0.024408 |
| b5_b7 | 0.804007 | 0.014438 | | b6_b7 | 0.787398 | 0.030042 |
| b1_b7 | 0.853382 | 0.027388 | | b3_b7 | 0.808295 | 0.039113 |
| b6_b7 | 0.819479 | 0.024749 | | b1_b7 | 0.832974 | 0.041694 |
| b2_b7 | 0.815379 | 0.024924 | | b2_b7 | 0.794330 | 0.043833 |
| b3_b7 | 0.819949 | 0.028169 | | b5_b7 | 0.777117 | 0.041537 |

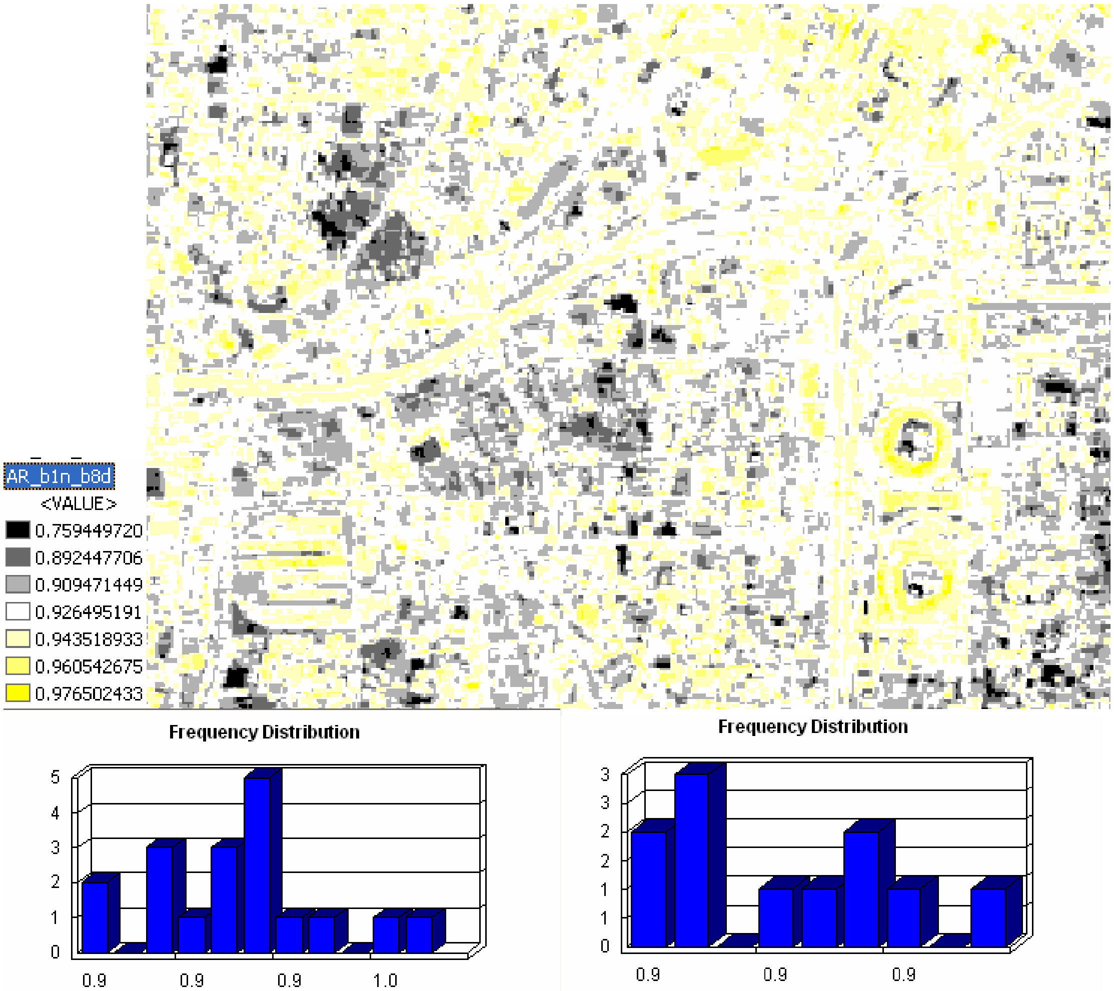


Figure 2. b1_b8 ranked high in being able to correctly identify roofs and pavements, but it is difficult to distinguish between the two cover types. The frequency distribution shows a tight clumping of NDTI values near 0.9 in a potential range of –1 to +1 for both pavements (left) and roofs (right).

When we rank the statistics by greatest difference in means, the NDTI combinations that are the best performers are very different. Table 3 presents the top five band combinations based on greatest separation of the means. From Table 3, it is clear that new thermal infrared bands dominate.

In our previous paper (McInerney et. al., 2006), an NDTI generated from bands 10 and 15 was identified as likely to be useful for distinguishing roofs and pavements. When compared with all other combinations, this particular ratio still appears to hold promise (Figure 3).

Table 3. Best NDTI when ranked by greatest difference between means.

| NDTI Band Combinations | Difference Between Means | Roof Standard Deviation | Pavement Standard Deviation |
|---|---|---|---|
| b10_b15 | .039 | .096 | .018 |
| b10_b14 | .038 | .033 | .016 |
| b12_b14 | .025 | .012 | .013 |
| b13_b14 | .023 | .012 | .005 |
| b13_b15 | .023 | .012 | .007 |

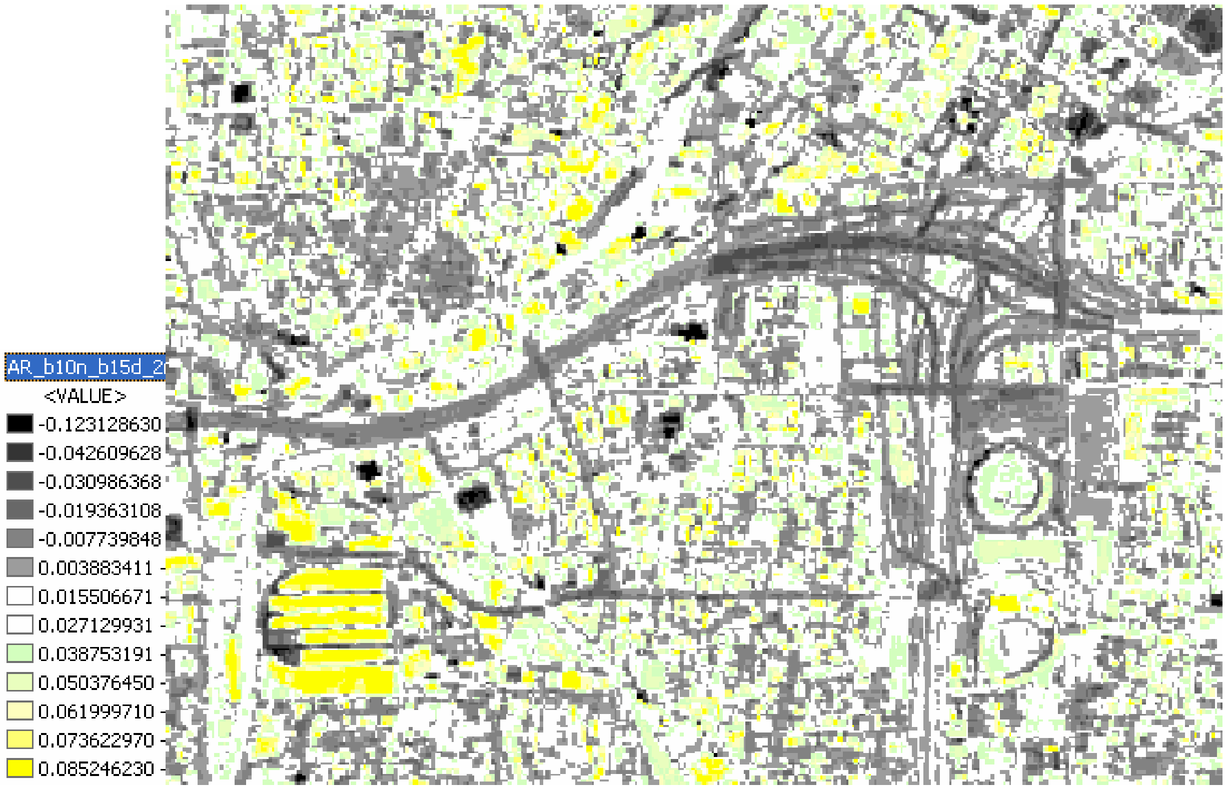


Figure 3. NDTI image based on Bands 10 and 15. The categories are 1/2 standard deviation intervals.

Another way of exploring the data is to rank the results by lowest average standard deviation of the roof and pavement standard deviations (i.e., best defined peaks). Table 4 lists the top combinations using the best standard deviation criteria.

Table 4. Best NDTI when ranked by lowest average standard deviation.

| NDTI Band Combinations | Difference Between Means | Roof Standard Deviation | Pavement Standard Deviation |
|---|---|---|---|
| b11_b12 | .0004 | .0027 | .0048 |
| b14_b15 | .0003 | .0087 | .0043 |
| b13_b14 | .0233 | .012 | .0051 |
| b13_b15 | .0230 | .012 | .0070 |
| b10_b11 | .0104 | .016 | .0042 |

The difference in the means for the first two combinations, b11_b12 and b14_b15, is very small (i.e., separation is poor). Yet notice that for both b13_b14 and b13_b15 the mean separation is nearly 100 times greater than the first two combinations. Furthermore, both b13_b14 and b13_b15 showed up in Table 3 when we ranked NDTIs by best difference between means. Since b13_b14 and b13_b15 appear in the top five of both rankings, the implication is that we are not making a large tradeoff when we adopt either a band 13-14 or band 13-15 combination as the best-performing NDTI.

Do the b13_b14 and b13_b15 NDTIs perform better than the previously-identified greatest difference between means choice, b10_b15?

Figure 4 shows the result, using the same classification scheme as in Figure 3 (based on 12 classes of ½ standard deviations). A comparison of the results in the two study areas suggests that the b13_b14 NDTI of Figure 4 more clearly represents a distinction between pavements and roofs. In particular, smaller street pavements are visible and the confusion between roofs and pavements appears to decrease (likely due to the tighter standard deviations).


Figure 4. NDTI image based on Bands 13 and 14. The categories are 1/2 standard deviation intervals.

### 2.4 Observations

Although the statistics and images show that the NDTI concept is viable, the physical explanation of why certain band combinations work well needs to be investigated. The physical basis of the Normalized Vegetation Index (upon which the NDTI is based) is well understood. The NDTI would be more readily accepted if research produced a corresponding first-principle physical rationale for its viability.

The NDTI is an initial step in the investigation of classifying urban structures through thermal remote sensing. A certain amount of confusion still remains in the resulting images. It is recommended that research on other image processing techniques (e.g., ratioing or principal components) be carried out to determine if an improvement over the NDTI technique can be found. An understanding of the first-principle physical rationale for the NDTI would help direct this work.

The principle advantage of the NDTI is that the consequences of atmospheric absorption and solar incidence angle are minimized because the result is generated from a single image in which these considerations are largely held constant.

The conclusions of this investigation are based on only a few ground-truth points in a single location. It would be advantageous to expand the investigation to other locations with different ground-truth points to verify the universal viability of the concept.

## CONCLUSIONS

Our previous research established the Normalized Difference Thermal Index (NDTI) concept and provided a demonstration of its efficacy.

For this study, we tested various band combinations of the ATLAS thermal spectral bands to determine how we might be able to use these bands to distinguish roofs from pavements, based solely on their thermal characteristics. The previous research proposed that two (NDTIs) be used, one to identify pavements and one to identify roofs. The best statistically-determined combination of bands was examined in detail. This research finds that the NDTI based on bands 13 and 14, and bands 13 and 15, provides the best tradeoff between correctly identifying pavement and roofs, and distinguishing between them. NDTIs from these bands produce well-defined images that accurately identify ground-truth points. (Refer to Figures 5 and 6.)

ATLAS Bands 7 and 8 (combined with other bands) were shown to be effective in correctly identifying pavements and roofs. However, they were not adequate in terms of distinguishing between pavements and roofs.

NDTI based on bands 13 and 14, and bands 13 and 15, provides the best tradeoff between correctly identifying pavements and roofs, and also distinguishing between them.

The longer-wavelength spectral bands were more effective at distinguishing between pavements and roofs. This means that imagers on currently available satellites cannot be used for this analysis.

The NDTI is a very useful concept because:

- It is easy to calculate.
- In order to generate the NDTI only a single source image is required.
- It is inexpensive to produce.

This study has successfully demonstrated that data from hyperspectral IR/Thermal sensors' bands can be used to distinguish urban features. These results can be incorporated with other technologies to provide automated decision support tools enhancing U-BE awareness for tomorrow's Future Force.

Figure 5. 3-D representation as determined from the NDTI of the Atlanta study area. Although not perfect, this image shows well the general urban structure as derived from only two thermal bands. (Note: This image is intended merely to make the roofs stand out. It is not representative of actual building height.).

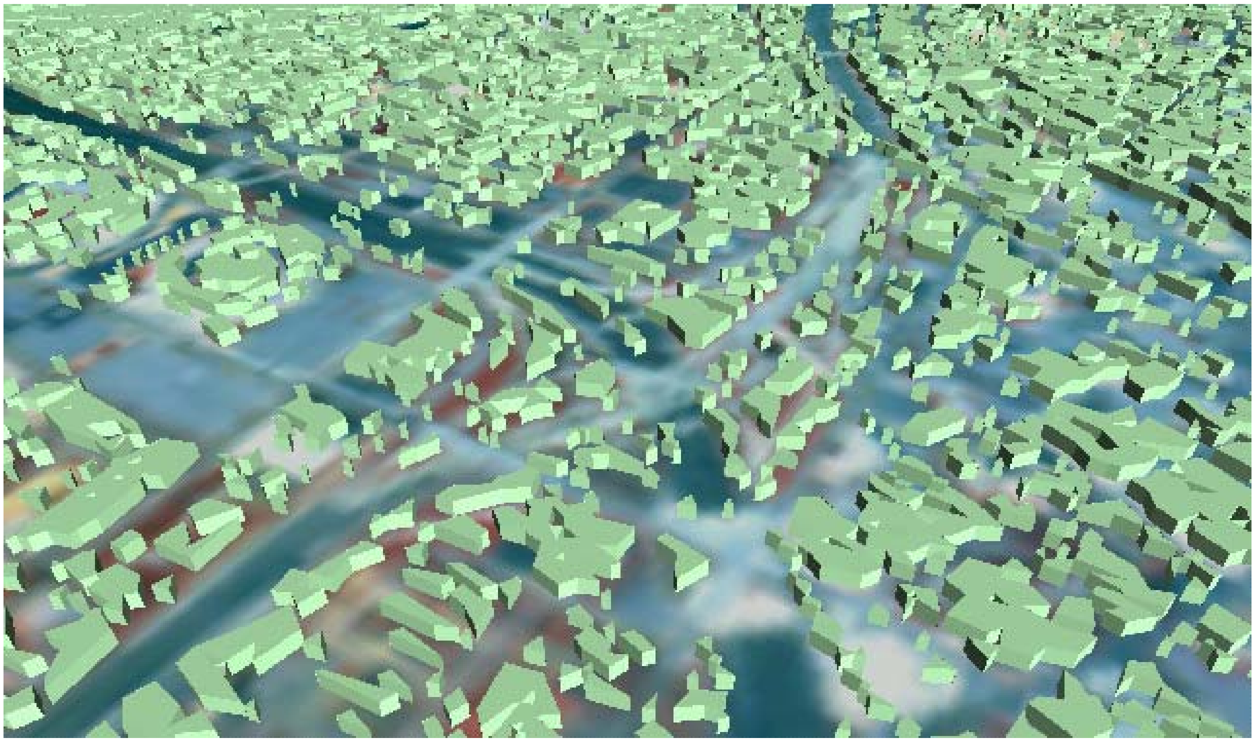

Figure 6. In this 3-D representation of the Atlanta study area (as determined by the NDTI), the viewer is flying southwest above the Interstate 75 corridor. The circular-shaped Turner Stadium appears at upper left. From this viewpoint, it is easier to see the curvilinear Interstate 20 (stretching diagonally from lower left to upper right). (Note: This image is intended merely to make the roofs stand out. It is not representative of actual building height.).

**ACKNOWLEDGMENT**

The authors would like to thank Dale A. Quattrochi, Ph.D. and Maurice Estes, Jr., both of the National Aeronautics and Space Administration (NASA) Earth and Planetary Science Branch at the George C. Marshall Space Flight Center, Huntsville, Alabama, for sharing their ATLAS data for Atlanta.

**REFERENCES**

Herold, Martin, Roberts, Dar A., Gardner, Margaret E., and Dennison, Phillip E. (2004). Spectrometry for urban area remote sensing – Development and analysis of a spectral library from 350 to 2400 nm, *Remote Sensing of Environment*, **91**, 304-319.

McInerney, Michael, Trovillion, Jonathan, Tarek, Abdallah, and Majumdar, Arjun, 2006: Classifying Infrastructure in an Urban Battlespace Using Thermal IR Signatures, Preprints, *25th Army Science Conference*, Orlando, Florida, U.S. Army (Acquisitions, Logistics & Technology), 8 pp.

Quattrochi, D., 2000: A Decision Support Information System for Urban Landscape Management Using Thermal Infrared Data, *Photogrammetric Engineering & Remote Sensing*, **66,** 1195 – 1207.