MONITORING WORLD-WIDE URBAN LAND COVER CHANGES WITH *ASTER*: PRELIMINARY RESULTS FROM THE PHOENIX, AZ LTER SITE [1]

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ABSTRACT

Detailed remote sensing of urban environments has been limited due to the poor spatial resolution of most satellite-based instruments and low demand from city officials and scientists. As many of the world's arid region urban centers continue to expand, the need to monitor urban land cover change and its impact on the surrounding environment becomes critical. The growth of urban ecology as an important field is evident with the awarding of the first urban Long-Term Ecological Research (LTER) projects to Phoenix, AZ and Baltimore, MD last year. The Phoenix LTER project relies heavily on remote sensing data products such as vegetation, soil, and urban cover types. In mid-1999 data from the newly-launched Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) instrument will be acquired twice per year for 100 large urban metropolitan areas. This monitoring will concentrate on cities in arid environments that are experiencing fast growth and facing potential environmental threats. Expected products of this effort are land use change, soil/rock/vegetation maps, and urban heat island monitoring.

1.0 INTRODUCTION

Urbanization of the arid regions of the southwestern United States is a comparatively recent phenomenon occurring largely in the last fifty years. The 1995 US Census identifies eight of the ten fastest growing cities and six of the fastest growing metropolitan areas as being located in the arid southwest. Arizona has been the second fastest-growing state in the nation for the past six years, and the Phoenix metropolitan area's population has doubled twice in the past 35 years. The urban fringe has expanded into former agricultural and pristine areas. A similar flow of population into large urban centers throughout the world's arid region is as dramatic (WRI, 1996). It is estimated that two-thirds of the global population will live in urban areas by 2025, up from less than one-third twenty ago. This increased pressure on the already fragile resources of desert regions has prompted the need for an accurate assessment of land cover and its change in these urban centers. It has also given rise to new areas of science such as urban ecology, urban remote sensing, and urban geology relating to hazard mitigation.

For many of these reasons, the National Science Foundation (NSF) awarded Arizona State University (ASU) the Central Arizona - Phoenix (CAP) LTER project. The primary objective of the 21-site LTER network is to monitor and assess long-term ecological change in diverse ecosystems in the United States. However, other LTER projects have focused on pristine locations well removed from the myriad effects brought about by extensive human modification and dominance of ecosystems. For the first time in the program, the CAP LTER study (along with the sister-project in Baltimore) provides a unique opportunity to monitor human-induced ecological changes resulting from rapid land-use transformations. Moreover, central Arizona is located at major geographic and climatic transition zones between the Sonoran and Chihuahuan Deserts, the Sierra and Rocky Mountain ranges. With less than 18 cm of annual rainfall, Phoenix is situated in a semi-arid landscape that provides excellent remote sensing opportunities due to minimal cloud and vegetation cover. However, this climate also produces a strong reliance on surface and groundwater sources, a high evaporation rate of moisture, and a continual threat of desertification. These same issues, faced by populations living on a one-third of the world's land surface, makes the relationships examined in this LTER relevant to people across the globe.

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A fundamental dataset required for ecosystem and land use change analysis consists of the major types of land cover and their areal percentages present in the study area. Land cover refers to the physical nature of the surficial materials present in a given area, whereas land use refers to the specific type of human use (Sabins, 1997). Collection of this data in the field can be very time-consuming and in some cases impossible for a large area. A more efficient approach is to use remotely sensed data of the study region with field verification to classify (or identify) land cover types (Anderson *et al.*, 1976; Hixson *et al.*, 1980). Once the land cover classification is obtained it can be used as an input into a variety of ecological models, and land cover maps can be constructed to aid in planning field sampling strategy. The land cover types can also be linked to different land use categories to investigate temporal and spatial changes in the urban ecosystem. On a global scale, such a data analysis effort can only be accomplished with extensive testing and technique development. In conjunction with the CAP LTER project, this has been ongoing in the Phoenix valley and preparations are underway to establish a similar monitoring effort in the future using the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) instrument. Scheduled for launch in mid-1999, the ASTER instrument will provide multispectral global data from the visible to the thermal infrared for the first time (Kahle *et al.*, 1991). ASTER is designed as three distinct spectrometers which will acquire data at spatial resolutions increasing from 90 m/pixel in the thermal infrared (5 bands) to 30 m/pixel in the short-wave infrared (6 bands) to 15 m/pixel in the visible (3 bands). One channel in the visible will also be collected at two different viewing angles providing the ability to generate DEMs.

2.0 METHODOLGY

2.1 *ASTER* STRATEGY

As part of the resource time of ASTER, data will be collected for specific global high priority investigations (volcano/glacier/urban monitoring, for example). The goal of the urban effort is to provide a dedicated observation strategy for urban environmental investigations around the world (Table 1). The project will study 100 of the largest urban centers, concentrating on those in arid and semi-arid environments (~ 75% of the targets). The chosen cities represent areas that are experiencing rapid growth and/or currently have populations of greater than one million people (WRI, 1996). These sites have been divided into high and low priority depending on factors such as projected growth rates, potential urban/environmental hazards, and the predicted success of ASTER observations (i.e., low cloud cover). Studies will be performed to monitor urban growth, land use change, impact on the surrounding environment, and the development of urban heat islands. The Phoenix metropolitan area will be the site of a major effort using ASTER data, serving as a calibration target and baseline for the remaining 99 cities.

2.2 LAND COVER CLASSIFICATION OF PHOENIX, AZ

2.2.1 Background Studies

The primary application of remote sensing data in this study was to provide a means for extrapolating detailed measurements at local sites to a regional context. Specifically, multispectral image classification will be used to identify land cover types, such as different grasses, crops, trees, soils, man-made materials, water, and native vegetation. Where used with field validation, the current airborne and satellite data, as well as the future ASTER data will provide accurate identification and estimates of the areal distribution of these different units (Howard and Christensen, 1998; Stefanov, *et al.*, 1998). These data can then be used to create regional land use thematic maps that depict different processes. For example, urban versus native materials, permeable versus impermeable surfaces, and transportation systems (asphalt and concrete materials) can be mapped.

A remote sensing dataset and processing techniques have been compiled during a NASA-sponsored pilot project on-going for the past three years in conjunction with the City of Scottsdale, AZ. Its goal was to study the use of thermal and visible/near-IR airborne data for the purposes of urban scene classification, environmental assessment, and change detection. These data sets are now being integrated into state and local activities to improve decision making and planning. For example, these classification algorithms and data have been used in surface impermeability studies for storm runoff assessment (Howard and Christensen, 1998). Specific test sites include a section of the downtown Scottsdale region mapped in high detail as well as the McDowell Mountains immediately east of the city. The later location is a region currently undergoing intensive study by state and local agencies to assess potential sites for urban development as well as preservation. These urban areas have provided excellent ground truth for the validation of the surface classification models and contain a time history of the expansion of the urban areas into pristine desert. Further, the addition of multispectral TIR wavelength bands provides the means to produce temperature maps to study the spatial distribution of heat islands. These data are critical inputs into micro and regional climate models which predict variations over time with changing land use and urban growth.

2.2.2 Landsat TM Image Processing

Landsat Thematic Mapper (TM) data was collected over the entire state of Arizona in May of 1993 and compiled into a georeferenced seven band mosaic. Multispectral TM data for the pilot study area (a 29 km x 29 km portion of east-central Phoenix and Tempe, AZ) was extracted from this mosaic. This region represents a small subset of the approximately 60,000 km^2 CAP LTER project area (Figure 1). A study area of this size necessitates the use of satellite data, as higher resolution airborne datasets do not yet exist for the majority of the site. The pilot region was selected as it contains a wide variety of urban, agricultural, and undisturbed land cover types.

Ratioing of several of the TM bands was performed in order to accentuate variations in pixel DN values corresponding to the different land cover types. Band ratios such as NDVI (Normalized Difference Vegetation Index) and SAVI (Soil-Adjusted Vegetation Index) have been defined in the literature to highlight changes in vegetation density and various geological materials (Elvidge and Lyon, 1985; Huete *et al.*, 1985; Sultan *et al*, 1987; Huete, 1988). The use of ratios also removes shadow effects caused by different degrees of surface illumination and reduces the topographic expression visible in a simple three band image. The TM ratio scheme used in the present work consists of: [band 5/band 7] in red, [band 5/band 1] green, and [(band 5/band 4) x (band 3/band 4)] in blue. These ratios highlight the presence of OH^- (frequently associated with clay minerals), low reflectance materials, and iron-bearing aluminosilicate minerals, respectively (Sultan *et al*., 1987). Although primarily a geologic discriminator, these ratios are also sensitive to variations in a wide variety of natural and manmade surfaces likely to be present in the CAP LTER project study area. The three band ratio image was used as the input data for the classification algorithm. All image processing and analysis described in this work was performed using ERDAS Imagine 8.3.1 running on a 250 MHz Sun Enterprise 3000 server.

2.2.3 Land Cover Classification Of TM Ratio Base Image

An unsupervised classification algorithm *(ISODATA)* (Vincent, 1997) was used for regions of the CAP LTER project area for which limited data (land use, aerial photographs, zoning maps) were available for accuracy assessment. These regions correspond to areas outside of Maricopa County, AZ and account for approximately 20% of the study area. Twenty or more classes are determined for each TM scene using the *ISODATA* algorithm, and these classes are assigned a land cover category on the basis of its ratio image signature, vegetation density, and geologic setting. Initial land cover categories were determined using field investigations of the pilot study region and analysis of the image signatures obtained from the ratio images. Land cover categories were further refined based on input from the various researchers involved in the CAP LTER project.

For the pilot project work presented here, a supervised classification approach was used because ground truth data were available in the form of field observations and various GIS datasets. Supervised classification algorithms rely on user-defined training regions that represent “pure” samples of a particular class. Minimum distance, parallelpiped, and maximum likelihood decision rules were tested for the pilot area, with the maximum likelihood decision rule obtaining the highest classification accuracy. Maximum likelihood algorithms assume a Gaussian distribution of pixel values within each training class and tend to be somewhat more accurate in regions of high surficial variability (Vincent, 1997). Image pixels that fall within a two-sigma standard deviation of the training class mean are assigned to that class. Training regions were defined for nineteen land cover classes using at least $10n$ pixels per training region, where n = six (i.e., the number of TM bands) (Jensen, 1986). Training region selection was based on ground truth data and band ratio signatures.

2.3 ARID HILLSLOPE SOIL DEVELOPMENT AND SEDIMENT TRANSPORT

In order to more fully quantify the thermal infrared spectral signature of soil development in the McDowell Mountains, spectroscopy and remotely sensed data were used to perform mineralogical analyses and rock/soil unit mapping. Airborne datasets used for this study were TIMS (Thermal Infrared Multispectral Scanner) and NS001 (Landsat TM simulator) collected in 1994 with a 4.5 m/pixel ground resolution. Using a linear deconvolution technique developed by Ramsey and Christensen (1998) mineral end-members from both laboratory and image emission spectra of soils were extracted. Deconvolution results of the laboratory emission spectra from the soils indicate that whereas major mineral end-members are detected with acceptable accuracy (80%), the percentage accuracy for those end-member was poor (2-100%) (Stefanov *et al.*, 1998). Application of the linear deconvolution technique to TIMS image spectra of soils has returned similar results. These preliminary results are still being investigated considering a more accurate result using a similar approach for aeolian sand transport (Ramsey *et al.*, 1998). Both investigations suggest that remotely sensed thermal infrared data such as provided by ASTER will be quite useful in creating detailed soil unit maps and for large scale studies of hill slope soil geomorphology. Results of this type are of particular importance in rapidly urbanizing arid areas where residential developments are encroaching on potentially unstable hill slope environments (Cooke and Doornkamp, 1990).

3.0 RESULTS

3.1 ACCURACY ASSESSMENT USING DIGITAL LAND USE DATA

The accuracy of any classification must be assessed prior to use in scientific analyses. Accuracy assessment involves the collection of ground truth data for the classified scene. This is done by establishing a number of test pixels within the image for which the actual ground cover is determined by field inspection, use of aerial photographs, and/or use of some other dataset (Congalton and Green, 1999). An overall classification accuracy is then determined by dividing the number of test pixels correctly classified by the number of total test pixels.

Assessment of accuracy for the Phoenix-Tempe pilot study area is not straightforward as the major dataset available for comparison is the 1995 digital Maricopa Association of Governments (MAG) Land Use Map (MAG, 1995). The temporal variation both between the two datasets as well as the current field validation results in errors at the rapidly developing portions of the region (i.e., the urban fringe). Use of the MAG dataset for comparison with classified TM data requires interpretation of the land cover types in terms of possible land use classes, which is complicated as several land covers may be associated with the same land use. Land use is the primary data format used by the various CAP LTER project researchers, therefore a fairly simple classification scheme based on the hierarchical model of Anderson *et al.* (1976) was defined (Table 2). It presents the CAP LTER project Level I (bold text) and Level II (normal text) land use classes defined for the Phoenix-Tempe pilot area and the corresponding land cover classes.

Examination of the 1995 MAG Land Use Map indicated that there was considerable potential overlap between the CAP LTER project and the MAG land use classes. For an accuracy assessment to be performed, a matrix was developed that matched the land use classes in each dataset. Figure 2 depicts this matrix for the Level I land use classes. A total of 256 randomly selected pixels located throughout the classified image were used for overall accuracy determination. No training regions were included in the accuracy assessment. The land cover classification (and its corresponding land use) for each test pixel was compared to the MAG land use classification using a georeferenced GIS layer and the correlation matrix illustrated in Figure 2. Overall accuracy of the maximum likelihood classification of the Phoenix-Tempe pilot area determined using this methodology was 71%.

There are a number of potential errors that may contribute to classification inaccuracy. As mentioned, temporal variation between the 1993 Landsat TM and 1995 MAG land use datasets may be significant for some classes, particularly vacant lots and agricultural areas. The resolution of the TM data also makes it difficult to separate distinct classes in areas of high land cover variability (i.e., mixed residential/commercial areas). Several land cover classes tend to have a similar band ratio signature (i.e., golf courses and parks) which leads to difficulty in statistical discrimination of these classes. For example, Howard and Christensen (1998) found that their classification accuracy for Scottsdale increased from ~ 69% using TM data to ~ 98% using 2.9 m/pixel NS001 data. The random pixel accuracy assessment technique may also be a source of error due to under sampling of classes throughout the image (Congalton and Green, 1999).

3.2 *ASTER* PREPARATION

Land cover classification of the Maricopa County portion of the CAP LTER study region is proceeding in a preliminary mode. Classification and verification of this region is continuing in order to refine the training class regions and obtain the maximum possible accuracy. Use of aerial photographs and ground truth measurements as reference data is expected to improve this accuracy, as is the use of a stratified random sampling scheme for accuracy assessment (Congalton and Green, 1999). Training class region sets will be defined for urban and undeveloped regions which can then be applied to Landsat TM datasets collected at various times to allow for temporal studies of urban change. Data fusion of high spatial resolution visible/near infrared, thermal infrared, and radar datasets will be investigated for use in determining highly accurate ground cover classifications for selected CAP LTER study sites.

Once the preliminary investigation of Phoenix, AZ using Landsat TM is completed, simulation of ASTER data will begin. Using Landsat TM, SPOT, and airborne data, resolution degradation will be performed. These datasets, similar in both spatial and spectral resolution to future ASTER data, will be classified for land cover using these techniques and assessed for accuracy. At the time of launch the infrastructure should be in place in order to perform detailed biannual studies for the global ASTER urban database. This project will acquire ASTER data over each city at least twice per year (both day and night observations) during the lifetime of the mission. Initially, data of Phoenix and the surrounding area will be used to aid in the LTER research project. Additionally, contact efforts will be initiated with government officials of the targeted cities and data will be stored at ASU and available for use by interested parties.

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Table 1. List of ASTER Global City Targets

City	Country	Priority	City	Country	Priority
Addis Ababa	Ethiopia	High	Lahore	Pakistan	High
Albuquerque	USA	High	Las Vegas	USA	High
Alexandria	Egypt	High	Lima	Peru	Low
Algiers	Algeria	High	Lisbon	Portugal	Low
Anchorage	USA	Low	London	England	Low
Amman	Jordon	High	Los Angeles	USA	High
Athens	Greece	Low	Madras	India	High
Atlanta	USA	High	Madrid	Spain	Low
Baghdad	Iraq	High	Manila	Philippines	High
Baltimore	USA	High	Melbourne	Australia	High
Bangkok	Thailand	Low	Mexico City	Mexico	High
Bamako	Mali	High	Miami	USA	Low
Barcelona	Spain	Low	Monterrey	Mexico	High
Beijing	China	High	Moscow	Russia	Low
Berlin	Germany	Low	Nairobi	Kenya	High
Bogota	Colombia	Low	New York	USA	Low
Bombay	India	High	Novosibirsk	Russia	Low
Brasilla	Brazil	High	Osaka	Japan	High
Buenos Aires	Argentina	Low	Paris	France	Low
Cairo	Egypt	High	Perth	Australia	High
Calcutta	India	High	Phoenix	USA	High
Cape Town	South Africa	High	Puebla	Mexico	High
Caracas	Venezuela	Low	Rangoon	Myanmar	Low
Casablanca	Morocco	High	Recife	Brazil	Low
Chicago	USA	Low	Rio de Janeiro	Brazil	High
Chongqing	China	Low	Riyadh	Saudi Arabia	High
Dakar	Senegal	High	Rome	Italy	Low
Dallas	USA	High	Salt Lake City	USA	High
Damascus	Syria	High	San Francisco	USA	Low
Delhi	India	High	San Diego	USA	High
Denver	USA	Low	San Paulo	Brazil	Low
Der es Salaam	Tanzania	High	Santiago	Chile	High
Detroit	USA	Low	Seattle	USA	Low
Edinburgh	Scotland	Low	Seoul	South Korea	Low
El Paso	USA	High	Shanghai	China	High
Guadalajara	Mexico	High	Singapore	Malaysia	Low
Guangzhou (Canton)	China	Low	St. Louis	USA	Low
Guatemala City	Guatemala	Low	St. Petersburg	Russia	Low
Havana	Cuba	High	Sydney	Australia	High
Ho Chi Minh (Saigon)	Vietnam	Low	Tashkent	Uzbekistan	High
Houston	USA	High	Tehran	Iran	High
Istanbul	Turkey	High	Tel Aviv	Israel	High
Jakarta	Indonesia	Low	Tianjin	China	High
Johannesburg	South Africa	High	Tokyo	Japan	High
Kabul	Afghanistan	High	Tucson	USA	High
Karachi	Pakistan	High	Tunis	Tunisia	High
Khartoum	Sudan	High	Urumqui	China	Low
Kinshasa	Zaire	High	Vancouver	Canada	Low
Kuwait City	Kuwait	High	Washington	USA	High
La Paz	Bolivia	High	Xianggang (Hong Kong)	China	Low

Table 2. CAP LTER Land Use and Land Cover Classes

Land Use Classes	Land Cover Classes
1a. open ground	
vacant lot	dry soil + grass ± concrete
graded lot	compacted soil
1b. natural	
metamorphic rock	metamorphic bedrock
granitic rock/soil	granitic bedrock + granular soil
dark rock/soil	varnished or basaltic rock ± soil
OH-rich rock/soil	hydroxide-rich minerals in rocks/soils
alluvial fan	desert vegetation + granular soil + mixed rock types
2. water	water
3a. riparian	
vegetated	vegetation + wet soil
3b. non-vegetated	
river gravels	mixed lithology cobbles and gravels
flood terrace	mixed lithology gravels + fine sediments
4. agriculture	
active	actively photosynthesizing row crops
fallow	standing or cut row crops, not actively photosynthesizing
5. recreational	
golf courses	grass + water ± sandy soil
parks	grass + woody vegetation ± soil ± asphalt
6. residential	
mesic	shingle or tile roofs + grass + woody vegetation ± water
xeric	shingle or tile roofs + granitic soil + woody vegetation ± grass ± water
with commercial	concrete + grass ± woody vegetation ± asphalt
7. commercial/industrial	
combined	asphalt + concrete + soil ± tar paper roofs ± metal roofs ± grass
industrial only	asphalt + concrete + soil ± tar paper roofs ± metal roofs
8. transportation corridor	
roadway	asphalt + concrete

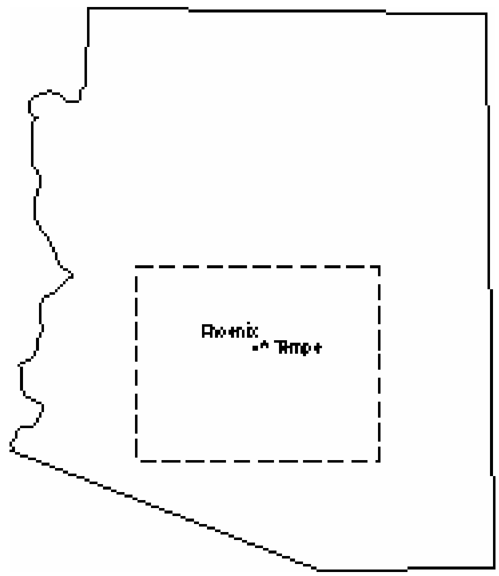

Figure 1. Location Map of the CAP LTER and Phoenix-Tempe Study Areas

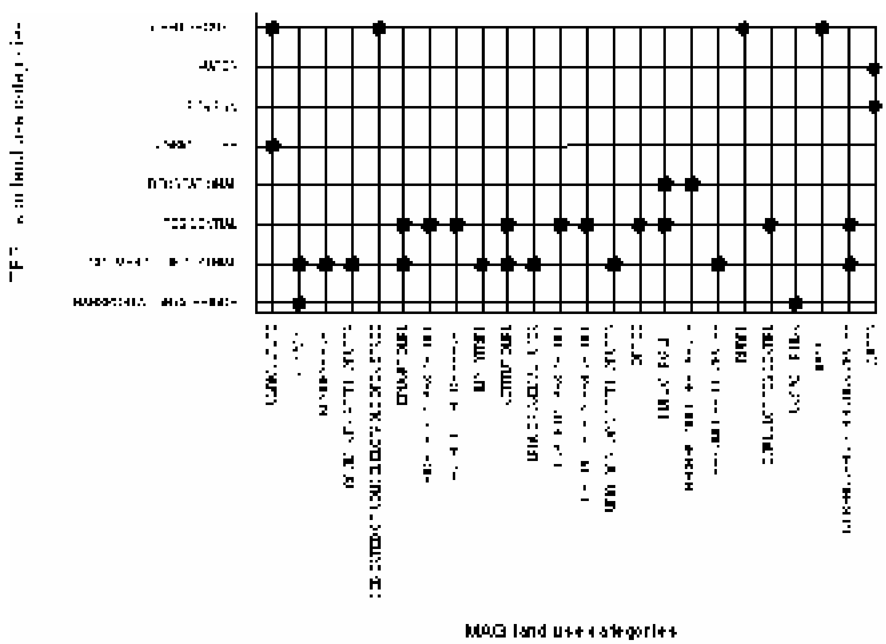

Figure 2. CAP LTER to MAG Land Use Correlation Matrix