

# CHARACTERIZING LANDCOVER CHANGES IN A RAPIDLY GROWING METROPOLITAN AREA USING LONG TERM SATELLITE IMAGERY

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## ABSTRACT

Most of the Land Use Land Cover classifications on a scale level of about 1:100.000 are static snapshots for a single date. They do not, in and out themselves, provide the ability to perform change detection monitoring. Satellite image data has been recorded during the past 30 years from sensors like Landsat MSS, TM and ETM+. Together with data from newer sensors such as ASTER these datasets represent a reliable database for long term change detection monitoring. A long term Land Use Land Cover change detection analysis was carried out for the Phoenix (AZ) region located in the Sonoran desert. The ideal classification scheme should be simple to use and easily adaptable to satellite scenes acquired by various sensors types taken in different years. The ideal outcome would be a flexible classification scheme which could be handled like a tool box, providing capabilities of tuning for some parameters. A first classification was obtained from Landsat MSS imagery using the standardized method of multispectral supervised classification. The results of this classification were poor with regard to classification accuracy. As an alternative we used an object oriented classification approach working in several steps. The whole image area was fragmented on several levels into image segments. We then defined classes and classification rules based on multispectral characteristics as well as on neighborhood relations. The change detection monitoring itself was carried out for a period from 1979 to 2000 in a GIS environment.

## INTRODUCTION

A number of various Land Use Land Cover (LULC) inventories based on the analysis of satellite remotely sensed imagery have been carried out for the U.S. as well as for the European Union throughout the past 10-15 years. The U. S. nation-wide analysis resulted in the National Land Cover Data dataset (NLCD 2000). The countries of the European Union adopted the Coordination of Information on the Environment (CORINE) Landcover Dataset (CLC 1990) based on an EU funded program launched in 1985. A second version of the CORINE CLC 2000 is now under a renewal process providing more detailed classes (Keil et al., 2003). Both datasets are a reliable source of information for a single “state of the moment” snapshot. NLCD is based on a series of Landsat Thematic Mapper (TM) imagery, recorded at several seasons throughout 1990-1995 and analyzed automatically using an unsupervised classification scheme and ancillary data sets. CORINE CLC 2000 also relies on satellite imagery obtained by the Enhanced Thematic Mapper (ETM+). The interpretation of the satellite data for the CLC 2000 was done manually; in addition the changes from 1990 to 2000 have been recorded.

Both datasets present a static inferred “snapshot” of ground conditions which prevents them, by themselves, from being useful for a detailed Land Use Land Cover Change (LULCC) detection monitoring for a specific region. The

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monitoring of geospatial changes over several time periods is however a matter of high interest. Dynamic transition processes are key interests in fields such as geography, ecology and sustainability research. Satellite imagery acquired over the last three decades under constant conditions with nearly identical sensor characteristics, provide a reliable source of information regarding LULCC. This enables a detailed monitoring of changes in a long term investigation.

In our research the growth pattern and processes of the greater Phoenix metropolitan area is analyzed. The beginning of the 1970s marked an increase in the population of Phoenix metropolitan area from 972.000 to 3.072.000 (an increase of 316%). This has resulted in a huge number of new built up areas primarily for residential purposes. The main topic of our investigation is the development of a robust, readily applicable and reproducible method that leads to accurate and reliable results regarding LULCC. Once the method has been developed and validated it will be applied on a series of satellite images. The results of this LULCC analysis then will be applied to a more spatially explicit analysis of the growth itself, the directions of growth over time and the transition processes from one land use class to another which characterizes growth in the Phoenix area.

## SATELLITE REMOTE SENSING IMAGERY

The area of interest (AOI) represents a rectangle with a size of 70 km by 112 km (7952 km<sup>2</sup>). For the LULCC we used images available from four different sensor types: Landsat Multispectral Scanner (MSS), Landsat TM/ETM+ and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The image data span a time period of 30 years (Table 1). The approximately five year time interval of the selected data represents a sufficient period to

**Table 1. Satellite Data**

year	MSS	TM	ETM+	NLCD	ASTER
1973					
1979					
1985					
1991					
1995					
2000					
2003					

gray: not analyzed; hatched: analyzed; NLCD: reference data

The spectra of the reflected energy measured by TM/ETM+ ranges from the visible to the shortwave infrared (see Figure 1). ASTER offers image data in three bands from visible green to near infrared with a ground cell size of 15 m. Six narrow bands in the infrared region record reflected energy at cell size of 30 m. The thermal or mid-infrared emitted energy is also measured by TM (one band, 120 m ground resolution), ETM (two bands, 60 m ground resolution) and ASTER (five bands, 90 m ground resolution).

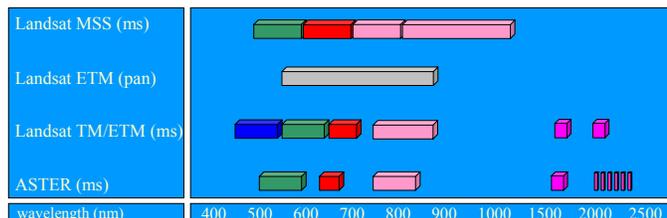
The AOI is covered by one single Landsat path and row (37/37) following the world reference system II (WRS II). Unfortunately the ASTER sensor does not cover the whole area in one pass due to a limited swath width of 60 km. For the year 2003 only one pass could be taken resulting in some lack of AOI coverage.

A large number of the TM/ETM+ scenes can be downloaded for free at the Earth Science Data Interface (ESDI, 2004) or ordered for a

detect significant changes in an urban area. All imagery was acquired during spring to early summer (March-June) except for the ASTER scene, acquired in October 2003. The spring/summer seasonal period was selected to minimize vegetation phenological change between the individual scenes.

Landsat MSS was the first operational orbital sensor and began acquiring data 1972. The MSS provides four bands from the visible green to the infrared portion of the electromagnetic spectrum with a ground cell size of 80 m. The Landsat TM/ETM+ series of data has been the “workhorse” for Earth observations since 1984 and represents the best historical and spatially extensive database for long term change studies.

**Figure 1. MS Optical Sensor Characteristics**



moderate price at Landsat.org (Landsat.org, 2004). For this investigation the MSS 1979, TM 1991 and ETM+ 2000 imagery have been downloaded from the ESDI site. This greatly facilitates the ability to access data for long term studies at little to moderate cost.

## IMAGE PREPARATION AND ANALYSIS

### Preprocessing of the Image Data

The satellite images are all georeferenced and projected to the Universal Transversal Mercator (UTM) geodetic system, located in zone 12 North. As the reference spheroid the World Geodetic System 1984 (WGS 84) was chosen for the projections datum. The relative geometric accuracy was checked out visually and is found within a distance of about 60 m (2 TM/ETM+ ms pixels). Cell sizes of the preprocessed output images for one ground pixel are: 57 m for MSS, 28.5 m for TM and ETM and 15 m for ASTER.

### Multispectral Image Analysis

Two main methods are available for the interpretation and analysis of remote sensing imagery: the statistical approach, based on the image histogram values and an image object based approach.

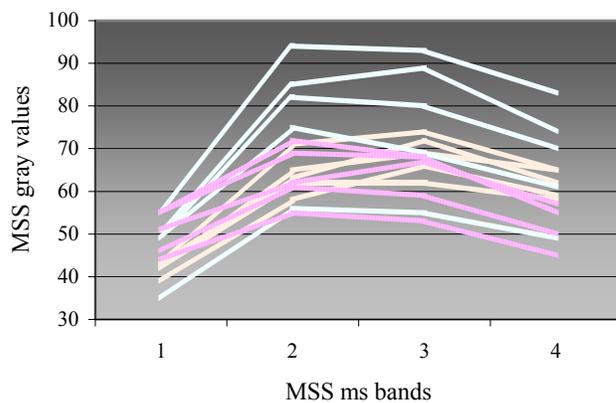
The multispectral classification (ms) can also be divided into a supervised and an unsupervised classification. For a supervised classification a number of training samples representing particular image features and desired output classes have to be collected manually. The statistics of these samples are used in the classification process as representatives for the classes. Several statistical rules have been developed and validated for use with remotely sensed data (Sabins, 1996). The unsupervised classification approach computes a user specified number of classes based on image band statistics.

**Table 2. Minimum Classes**

Upper Class	Natural Land	Farmland
Subclass	vegetated	vegetated
Subclass	bare soil/rock	fallow
Upper Class	Urban	Water

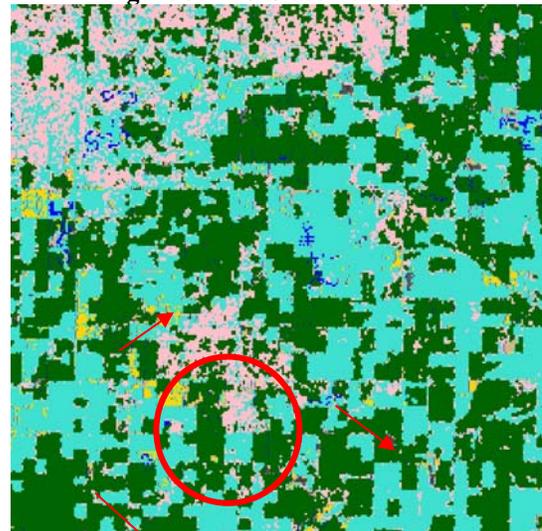
We extracted LULC classes following the classification scheme (level I) developed by Anderson et al. (1976). For the AOI of Phoenix the classes listed in Table 2 were chosen. The MSS image from the year 1979 was selected for an initial classification using the ms supervised classification approach. In addition to the original four band values a Normalized Differenced Vegetation Index

**Figure 2. Reflectance Curves of Surfaces**



pink: urban, turquoise: fallow farmland,  
beige: natural soil/rock

**Figure 3. MS Classification**



green: vegetated farmland, turquoise: fallow farmland, pink: urban, blue: water, yellow: bare soil/rock; outlined: City of Chandler; arrows indicate misclassifications; size: 25 km<sup>2</sup>

(NDVI) was calculated for the MSS data. The overall results obtained from several classification iterations did not produce reliable and satisfying results. The lack of differentiation of feature classes with closely related reflectance values particularly led to unacceptable misclassifications. As an example we will focus on the classes ‘fallow farmland’, ‘natural soil, rock’ and ‘urban’. The reflectance values for 15 randomly selected samples are shown in Figure 2 (the color coding is the same as in Table 2). It is obvious that the spectra for all three classes are completely mixed. All of the classes are spectrally similar regarding their reflectance in the four-band MSS data.

The values in the sample plot (Figure 2) range from 37 to 95 on an eight bit scale. These values of course do not represent the original reflectance values recorded by the MSS sensor. The original data have been stretched from a 6-bit to an 8-bit gray level range during preprocessing. The same misclassification can be recognized for the classes ‘farmland vegetated’ and ‘natural land vegetated’. Reflectance values of these two classes are also very similar. They can be identified clearly by a human’s eye using their individual location and neighborhood relations. These relationships are not included as part of the supervised ms classification process however. Another factor affecting these two classes is climate variation (CLINO 2004). Spring 1979 was a relatively humid season compared to the long term mean average precipitation. This extraordinary amount of rainfall led to a strong increase of vegetation cover in natural lands. This in turn increased the spectral similarity of natural lands to vegetated farmland.

Assessment of the ms classification results carried out by a random sampling method leads to unacceptable overall accuracies of less than 63%. Several examples of the inaccurate classification can be clearly identified in Figure 3. The subset shows an area mostly under farmland use indicated by green tones. Urban use is coded with a pink color. Misclassification can be detected at the edges of farmland where the class ‘urban’ is indicated (red arrows in Figure 3). An urban area should appear as a unique region without any farmland use inside. Reliable ms-classification results for this area have been carried out by using TM imagery and additional data in a knowledge based classification process (Stefanov et al., 2001).

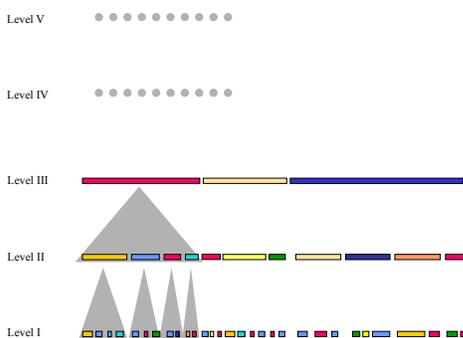
These following factors were identified as leading to the coarse ms classification results for the MSS imagery:

- the small 6-bit range of reflectance values
- the number of spectral bands is limited to four
- the ground resolution of 80 m is relatively coarse leading to problems in finding object boundaries

### Object Oriented Image Analysis

Another and relatively new approach for image analysis utilizes not only measured reflectance values but also neighborhood relations (object oriented analysis) and brings out promising results for the analysis of urban regions (Kressler et al., 2003). It is based on a three-step workflow. In the first step image segments are calculated. These segments are spectrally homogeneous clusters calculated from initial seed points. The interpreter is forced to define parameters for the clusters based on the scale, spectral properties and shape properties of the output segments. These image segments have to be calculated on several hierarchical levels following an iterative ‘trial and error’ process. The

**Figure 4. Hierarchical Segmentation Scheme**



final image segments should represent the single objects of interest as best as possible. An essential characteristic of an object oriented approach is that each image segment is connected to its neighbors on the same level of hierarchy, as well as to its ‘parent super objects’ on upper hierarchical levels and to its ‘child sub-objects’ on lower levels (Figure 4) (Batz, 2000). In a second step of the segment-based classification the classes have to be named, a color for each class has to be assigned and the ‘class heritage’ has to be defined. Classes can be found not only on one level but also on other levels of segmentation. For example, a class ‘urban’ can be found on a relatively rough upper level. A deeper sub level may consist of subclasses from the parent class ‘urban’ like ‘dense urban’, ‘sparse urban’ and ‘industrial urban’. All these three subclasses are also directly linked to each other (Blaschke, 2000). The

third and most work-intensive step is the definition of appropriate class parameters or rules for a best description of the desired output classes. For reliable classification results the most typical and best describing class parameters have to be tested for each class.

Therefore the object oriented segmentation based software package offers a huge number of standardized tools:

- the layer values,
- shape parameters,
- texture parameters,
- hierarchy and neighborhood related parameters and
- class related parameters.

All these descriptions can be used for a specification of single classes. In addition the class description parameters can be enhanced by the use of a tool for ‘customizing features’. This tool box is based on all standardized tools, but enables the use of logical expressions as a means of defining classes. The definition of useful class description parameters is refined by iterative cycles with a number of feedbacks coming from each classification run. In some cases it is also necessary to subdivide a unique class into two or more subclasses. Each of the subclasses is defined by one or more different describing parameters. The software allows the definition of hard-coded classes but also provides the capability to use fuzzy classification rules. This allows for smooth overlap regions in terms of class definitions between two classes with connate attributes.

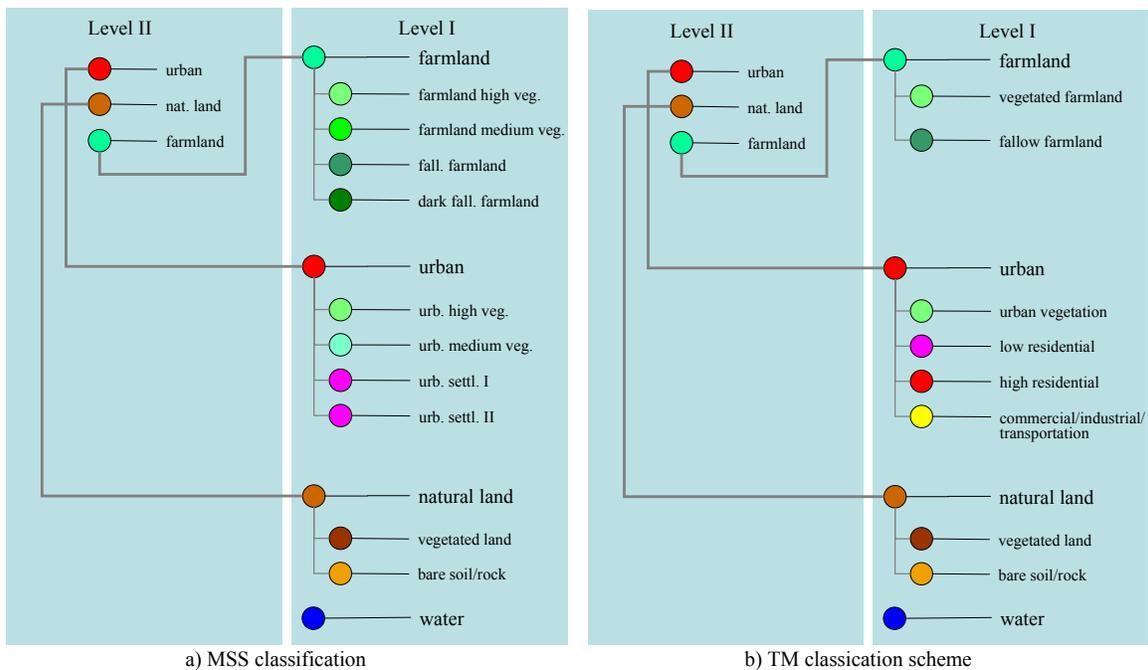
### Object Oriented Image Analysis-Segmentation

As outlined above the segmentation process was performed using individual parameters for each scene. For the MSS 1979 scene all ms bands were used. The TM image of 1985 was segmented using selected bands on each level. Landsat TM 1991 image consists of an exception: the pan band of the ETM+ 2000 scene was used only for the calculation of segments because of its higher 15 m resolution. A separate band containing the information of the NDVI was also computed and used as input information for both image segmentation and classification.

### Object Oriented Image Analysis-Classes and Classification Rules

The main goal of this investigation is the definition of a classification scheme that is useful for all scenes of all sensors. The desired classification should include the minimum classes outlined in Table 2 and should provide more detailed analysis results from imagery with improved image capabilities. For the MSS 1979 scene the class-scheme was defined as shown in Figure 5a. On segmentation level II, which consists of relatively large image segments, the three

**Figure 5. MSS/TM Classification Scheme**



upper classes ‘farmland’, ‘natural land’ and ‘urban’ were classified by a manual interpretation. This human interpretation process can be carried out quickly and outlines roughly the boundaries of each upper class. At this stage the classes do not have any class defining parameters.

The classification into several subclasses was performed based on the level I segmentation with an added fuzzy expression. Each subclass belongs to its upper class with a very high probability. In case of overlaps e.g. the subclass ‘vegetated farmland’ is classified as an urban class on the rough upper level, the spectral reflectance of the feature is weighted higher than the manual classification using the fuzzy rule. The subclasses were defined using parameters mostly dependent on spectral values (see Tables 3 and 4, abbreviations correspond to the classes listed in Figure 5 a+b). In the MSS 1979 scene ‘farmland’ could be divided into ‘vegetated farmland’ and ‘fallow farmland’. These objects

**Table 3. Class Definition for the MSS 1979 scene**

ms & custom- mized features	veg. farm.	fall. farm.	low int. res.	high int. res.	comm., indust., transp.	nat. land v.	bare soil/rock	water
bd. 7 – bd. 5/ bd. 7 + bd. 5			x	x	x		remaining	
bd. NDVI	x	x				x	remaining	x

**Table 4. Class Definition for the TM and ETM scenes**

ms & custom- mized features	farm. high v.	farm. med. v.	fall. farm.	dark fall. farm.	urb. high v.	urb. med v..	urb. sett. I	urb. sett. II	nat. land v.	bare soil/rock	water
bd. 3/bd. 2	x	x	x		x	x			x	remaining	
bd. 2/bd. 1			x							remaining	
bd. 3/bd. 1				x						remaining	
bd. 1/(bd. 2+bd. 3+ bd. 4)										remaining	x
brightness/bd. 1							x	x		remaining	

could not be separated using one definition class for each expression because overlaps to other classes occurred. The class ‘vegetated farmland’ for example was separated into one class consisting of high values in the MSS band 3 and another class with medium reflectance values in the same band. Every subclass of the ‘farmland group’ (level I) belongs to the upper class ‘farmland’ (level II) and does not belong to either ‘urban’ or the ‘natural land’ upper class. The same rules used for the definition of the class ‘vegetated farmland’ were applied to the class ‘urban vegetation’. But this class belongs strictly to the upper class ‘urban’ on level II. A special definition was developed for the detection of urban settlements. This class ‘urban settlement II’ is defined by the expression ‘bordering directly the class urban settlement I’. Following application of this expression former unclassified spaces in urban areas (level II) were then classified correct as ‘urban settlements’. The class ‘water’ was classified on level I without any dependencies to an upper class. For the TM scenes with higher ground resolution and improved spectral and radiometric capability the same upper classes were used for a definition of rough land use types. Other sub-classes with a higher degree of differentiation could be identified compared to the MSS data. In particular the class ‘urban’ could be divided into the sub-classes ‘high residential’, ‘low residential’ and ‘industrial, commercial, transport’ following the scheme of the NLCD 2000. We also tried to improve the TM classification using other NLCD 2000 classes for ‘vegetated farmland’ such as ‘pasture hay’, ‘row crops’ or ‘small grain’. We could not gather actual ground verification of these classes for the time the satellite data has been acquired however. The differentiation between vegetated farmland and fallow farmland used for the MSS 1979 data was therefore retained.

### Classification Accuracy Assessment

A relative accuracy assessment of the classification results was carried out for the TM 1991 classification. We used the NLCD 2000 data set as a source for verification. Each subclass of our classification was tested with 20 randomly distributed points of the NLCD 2000 classification. This led to an overall mean classification accuracy of 87% and can be accepted as an initial result. A more rigorous accuracy assessment is necessary to fully validate the classification results.

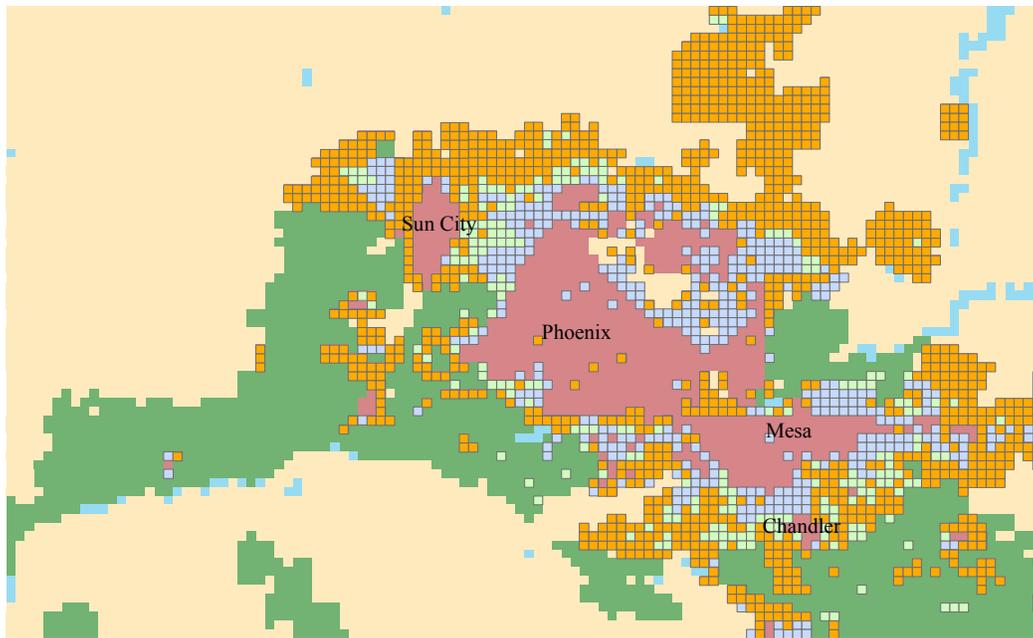
## ANALYZING CHANGES

Each classification was transferred into a GIS (Geographical Information System) environment. In the GIS an overlay was performed with a mesh. This mesh consists of an equal spaced 1 km<sup>2</sup> grid. The majority classes of the underlying satellite image classification were assigned as an attribute to each cell of the mesh. Changes in the majority class attributes for each grid cell were assigned different colors for visualization purposes. These colored grid cells indicate the LULCC over 21 years in time steps of approximately five years (Figure 6).

The Phoenix metropolitan area in 1979 consisted of a large central urban region and several isolated urban areas around it. The majority of urban growth occurred in the north-western portion of the Phoenix metro area until 1985. Overall urban growth at boundaries can also be identified as an indicator of aggregation into a more contiguous regional metropolitan area. The corridors between Phoenix metropolitan area proper and the isolated smaller cities were mostly under agricultural use in 1979. These corridors have now been built up and converted to residential use. The gap between Phoenix and the City of Chandler in the southern portion of the metropolitan region closed between 1979 and 1985. During this time urban settlement was established in the northwestern portion of the metro area. The main transition process was from farmland to urban residential use.

The period from 1985 to 1991 continued the increase of urban settlement in the northwest and bridged the gap between the cities of Phoenix and Sun City. Expansion of urban settlement west of Sun City continued during this time period. The transition process again mainly focuses on a change from farmland to urban residential use.

**Figure 6. LULCC 1979 - 2000**



Legend: green=farmland; red=urban; beige=natural land

blue outlined cells=not urban 1979 urban 1985; green outlined cells=not urban 1985 urban 1991

orange outlined cells=not urban 1991 urban 2001; underlying MSS 1979 classification

During the 1990 significant growth continued in the northeastern part of Phoenix metropolitan area as well as in

the east associated with expansion of the City of Mesa. The major transition process in the northeast was from natural lands directly to urban use during 1991-2000. Individual cities observed in 1979 are now contiguously aggregated within the greater Phoenix metropolitan area. Growth to the west of Sun City is also now connected to the rest of the metropolitan area and is continuing westward. A number of new currently isolated areas (such as the Anthem development located in the north of the current urban fringe) will doubtless one day become spatially contiguous with the existing metropolitan area.

## SUMMARY AND OUTLOOK

A new method basing on image segmentation in combination with an object oriented and rule based classification scheme leads to reliable classification results. The defined algorithm was adapted successfully to image data of three satellite sensors from the Landsat series: MSS, TM and ETM+ respectively. LULC classification for a period of 21 years has been established for the metropolitan area of Phoenix. LULCC has been analyzed and visualized in a GIS environment. The next step will be an analysis of 1973 MSS data as well as classification of image data recently acquired by the ASTER sensor in Fall 2003. It is of great importance to adapt the classification scheme to these image data, in particular the ASTER information. Due to the malfunction and disability of the Landsat ETM sensor since the end of 2003, ASTER data can fill in data gaps resulting from this malfunction. ASTER data will also provide continuity with the proposed Landsat continuity mission.

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## REFERENCES

- Anderson, J. R., Hardy, E. E., Roach, J. T. and R. E. Witmer (1976). *A Land Use And Land Cover Classification System For Use With Remote Sensor Data*. Geological Survey Professional Paper 964. United States Government Printing Office, Washington, <http://landcover.usgs.gov/pdf/anderson.pdf>.
- Baatz, M. and A. Schaepe (2000). *Multiresolution Segmentation: an optimization approach for high quality multi-scale image segmentation*. In: Strobl, J. et al. (Edts.): *Angewandte Geographische Informationsverarbeitung XII. Beiträge zum AGIT-Symposium Salzburg 2000*, Karlsruhe, Wichmann, pp. 12–23.
- Blaschke, T., Lang, S., Lorup, E., Strobl, J. and P. Zeil (2000): *Object-oriented image processing in an integrated GIS/remote sensing environment and perspectives for environmental applications*. In: Cremers, A. and Greve, K. (Edts.): *Umweltinformation für Planung, Politik und Öffentlichkeit / Environmental Information for Planning, Politics and the Public*. Metropolis Verlag, Marburg, Vol 2: pp. 555-570.
- CLINO (2004). <http://www.worldweather.org/>
- ESDI (2004). <http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp>
- Hofmann, P. and W. Reinhardt (2000): The extraction of GIS features from high resolution imagery using advanced methods based on additional contextual information – first experiences. In: *Int. Arch. Photogramm. Remote Sensing*, Vol. XXXIII, Amsterdam, 2000.
- Keil, M., Mohaupt-Jahr, B., Kiefl, R. and G. Strunz (2003). Update of the CORINE Landcover Database in

- Germany. *Int. Arch. Photogramm. Remote Sensing* XXXIV, 7/W9, WGVII/4, Regensburg, June 27-29 2003, pp. 72-77.  
[http://www.caf.dlr.de/caf/anwendungen/projekte/projekte\\_nutzung/corine/x\\_images/urs2003\\_clc2000\\_Keil\\_et\\_al.pdf](http://www.caf.dlr.de/caf/anwendungen/projekte/projekte_nutzung/corine/x_images/urs2003_clc2000_Keil_et_al.pdf)
- Kressler, F., Y. Kim, K. Steinnocher (2003): Object-oriented land cover classification of panchromatic KOMPSAT-1 and SPOT-5 data. *Proceedings from IGARSS 2003 IEEE*, Toulouse, July 2003, [http://www.definiens-imaging.com/documents/publications/I\\_D01\\_19.pdf](http://www.definiens-imaging.com/documents/publications/I_D01_19.pdf).
- Landsat.org (2004). <http://www.landsat.org/>
- NLCD 2000 (2004): <http://landcover.usgs.gov/prodescription.asp>
- Sabins, F.. (1996). *Remote Sensing: Principles and Interpretation*. W H Freeman & Co., New York.
- Stefanov, W.L., Ramsey, M.S., and Christensen, P.R. (2001). Monitoring urban land cover change: An expert system approach to land cover classification of semiarid to arid urban centers, In: *Remote Sensing of Environment* 77 (2), pp. 173-185.