

REMOTE SENSING FOR THE MONITORING OF URBAN GROWTH PATTERNS

M. S. Moeller

IIS, ASU, International Institute for Sustainability, Arizona State University, Tempe, AZ 85287-3211
matthias.moeller@asu.edu

KEY WORDS: urban growth, urban change, urban development, ASTER, ETM, TM, MSS, object oriented, segmentation

ABSTRACT:

Urban areas are the most dynamic region on earth. Their size has been constantly increased during the past and this process will go on in the future. Especially in less developed countries a strong trend towards concentration of people in urban areas can be observed. To understand urban growth remote sensing imagery is a reliable source. A long term growth study for the Phoenix, AZ metropolitan area was carried out on a mid scale level for a period of 30 years. This study used satellite imagery from several sensor systems and an object oriented image analysis and classification approach. The change results of the six periods investigated have been analyzed in terms of growth direction and distance. Overall several typical growth stages could be assigned to the development of the city. The outcome could be a basis for the comparison of different cities with the same scheme.

KURZFASSUNG:

Urbane Siedlungsräume zählen zu den Regionen mit der größten Dynamik auf der Erde. In der Vergangenheit sind Städte permanent gewachsen und werden dies auch zukünftig. Besonders in Entwicklungsländern kann man ein starkes Wachstum der Städte beobachten (Landflucht). Um das Wachstum dieser Stadtregionen zu verstehen, bieten sich Fernerkundungsdaten an. In einer Langzeituntersuchung der Stadtregion Phoenix, Arizona, wurde in einem mittleren Maßstabbereich das Wachstum über einen Zeitraum von 30 Jahren untersucht. In dieser Studie wurden Satellitenbilder unterschiedlicher Sensoren verwendet und mit Hilfe einer Objekt-orientierten Methode der Bildanalyse ausgewertet. Die Änderungen der sechs untersuchten Perioden wurden anschließend auf Wachstumsparameter hin untersucht (Richtung und Entfernung vom Stadtzentrum). So konnten typische Phasen des urbanen Wachstums aufgezeigt werden. Der entwickelte Algorithmus kann als Grundlage zum Vergleich für unterschiedliche Städte herangezogen werden.

1. INTRODUCTION

Cities and urbanized areas are the social centers of our modern life and they provide all of our daily needs. They promise security, welfare and a place where people may find better life conditions compared to rural areas. As a consequence urbanized areas have become the densest populated regions on earth over the past (United Nations, 2002).

The world human population has been more than doubled during the past 50 years, passing the 6 billion mark in 2000 and now approaching the 6.5 billion mark. This overall growth is mainly driven by the growth of population in less developed countries; however the number of people living in developed countries remains more or less the same and is predicted to decrease in the second half of this century.

The concentration of people in very dense populated urban areas mainly located in less developed countries highly recommends the introduction of sophisticated monitoring systems for these regions. Those will be used mainly for planning purposes and should enable reporting the overall growth of urban areas on a detailed level. It should also enable the comparison of different cities in terms of growth. These are the main questions such a system should help to answer: where are the geographic locations of growth, what kind of development can be observed and where are the initial seed points of growth?

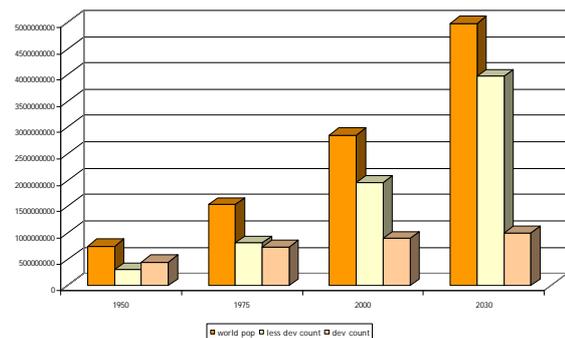


Figure 1. Growth of urban population

Especially less developed countries often neither have the infrastructure and capabilities which are necessary for a modern city planning nor do they have experts for a permanent mapping and in field surveying of the urbanized regions.

2. DEMANDS FOR REMOTE SENSING

Remotely sensed imagery in some cases may be the only reliable source for a sufficient monitoring. Satellite acquired image data provide a synoptic overview for large regions recorded always with a standardized and calibrated monitoring system. The imagery may be recorded frequently with a high

temporal resolution. Image archives store a large number of satellite remote sensing imagery starting in the early 1970 and increase the data by daily means. These data is available mostly for free and enables a historic view back to the past. By analyzing ancient imagery time series of Land Use Land Cover Changes (LULC) can be generated and than be used for the prediction of future development as well as for the verification of growth model output. Several programs have been introduced to enable free access to image data even for less developed countries (TRFIC, 2005).

2.1 Spatial Resolution and Application Scale

The spatial resolution or the ground cell size of one pixel as the finite image element is the most important characterization for a remote sensing image. On the one hand, as higher the spatial resolution as better the interpretability by a human observer will be. On the other hand a very high resolution led to a high object diversity which could end up in problems when an automated classification algorithm is applied to the data. For urban monitoring -in terms of urban growth detection- a scale of about 1:25.000 – 1:50.000 should be adequate (Sabins, one more). This application scale can be achieved from sensors which providing a spatial resolution of 4m through 50m (according to the grey color in Table 1).

pixel size in (m)	Definition	Platform	Application Scale
0,1-0,5	extremely high res.	airborne scanner, aerial photos	1:500 - 1:5000
>0,5-1,0	very high res.	Ikonos (ms), Quickbird (pan)	1:5000 - 1:10000
>1,0-4,0	high res.	Ikonos (ms), Quickbird (ms)	1:10000 - 1:15000
>4,0-12	medium res.	IRS (pan), SPOT (pan)	1:15000 - 1:25000
>12-50	low res.	ASTER, IRS (ms), Landsat (pan, ms), SPOT (ms)	1:25000 - 1:100000
>50-250	very low res.	Landsat MSS	1:100000 - 1:500000
>250	extremely low res.	NOAA	> 1:500000

Table 1. Application Scale for various remote sensing images (changed after Neer, 1999)

2.2 Spectral Properties

Most artificial urban surfaces consist of concrete, tar, asphalt and burned clay, wood or metal plates (all used for roofs). Other regions in urban areas appear more natural either not altered and covered by bare soil or with vegetation. This mixture of different materials is often contained in one pixel, a so called 'mixed pixel'. That makes it hard to detect and to differentiate clearly between objects surfaces and at least objects themselves. The ideal solution would be a hyper-spectral scanner with a large number of bands each with a small bandwidth of 10nm. But these remote sensing systems are limited and mainly in an experimental stage. Hyperion as a satellite sensor providing a 30m spatial resolution and 200 spectral bands each with a 10nm bandwidth ranging from 400nm through 2500nm. (Hyperion, 2005). Aviris, an aircraft mounted sensor system, provides a ground resolution of 17m, 224 spectral bands each with a width of 10nm, ranging from

400nm through 2450nm (Aviris, 2005). CHRIS (Compact High Resolution Imaging Spectrometer) is another experimental hyperspectral satellite recording images with a pixel size of 18m spatial resolution in individually programmable bands each with a 10nm bandwidth (CHRIS, 2005). Unfortunately these three hyperspectral imaging systems are and not available for an operational use yet.

The sensor system with the highest spectral resolution available on a more or less operational base nowadays is the ASTER sensor (Advanced Spaceborne Thermal Emission and Reflection Radiometer) offering 14 bands in the visible, infrared and thermal portion of electromagnetic energy (Asterweb, 2005). ASTER has been launched in December 1999 as part of NASA's Earth Observing System (EOS). Designed primarily as an experimental sensor, ASTER nowadays becomes a more and more operational system.

2.3 Temporal Properties

The temporal resolution is another important factor especially when studying urban areas. An ideal solution would be a sensor system recording permanent the entire earth and delivering this data in real time. But due to technical restrictions such a system can not be realized. As better the temporal resolution becomes as coarser will the spatial resolution. Geostationary satellite sensors like the Meteosat weather satellite series are placed over the equator and orbit the earth in 24 hours. They offer spatial resolutions of about 7 km and send real time images covering the entire earth from the North Pole to the South Pole every 30 minutes. Of course that imagery is not useful for urban remote sensing purposes. Polar orbiting systems like Landsat and ASTER typically offer repetition cycles of 16 days. SPOT (Système Probatoire d'Observation de la Terre), Ikonos and Quickbird provide side looking capabilities and can be rotated off their horizontal axis facing cross track with various angles to the left and the right respectively. This increases the repetition cycle up to three days. However, this side looking images do not provide a true nadir view limiting their usage in urban areas sometimes. Another factor in terms of temporal resolution is the actual cloud coverage. In tropical regions with a dense layer of clouds, an undisturbed view to the ground is limited. In these regions satellite sensors with synthetic aperture radar capabilities may be the best solutions and have been successfully used for urban studies (Henderson, 1982).

2.4 Accessibility

The Landsat sensor series does have a long lasting history of image acquisition. Actually it is the only series of remote sensing sensors acquiring imagery of a scale which is useful for an urban monitoring. Since the Landsat series has been launched in 1972 with the first Multispectral Scanner (MSS), imagery has been recorded permanently and have been stored in data archives. Due to their more than 30 years period of operation these data are from very high value in terms of long term change detection monitoring. Most of the data are available for a low charge and handling fee, some of them are free for download through the internet. Good starting points for a search for satellite imagery can be found at ESDI 2005, USGS 2005, Landsat 2005, EOS Webster 2005.

3. APPLICATION OF REMOTE SENSING FOR URBAN GROWTH – THE PHOENIX METRO AREA

One of the regions with the highest growth rate world wide is the Phoenix metropolitan area (PHX). It is located in the south west of the United States and is part of the Sonoran desert. Desert fauna and flora are highly adapted to the extreme climate and draught and is very sensitive to disturbances. However the PHX metropolitan area is the sixth largest urban area in the U.S. and is still rapidly expanding. This growth has been monitored over the past 30 years in this study using remote sensing.

3.1 Area of Interest and Satellite Data

Extend of the area of interest is about 112km and 72km in x- and y- direction. The central part of the area belongs to the city of Phoenix and its neighboring cities. The urban body is surrounded mainly by farmland 1973, some parts of the area of interest belong to Indian reservation and others to natural reservations. Overall seven different satellite imagery acquired from 1973 – 2003 have been used in this research. All of the data has been recorded in spring time during a six - weeks period, making sure the overall phenology is about the same for all scenes.

sensor	date acquired	sensor	date acquired
MSS	05.05.1973	TM	18.03.1991
MSS	01.04.1979	TM	13.03.1995
MSS	24.03.1979	ETM+	19.04.2000
TM	04.05.1985	ASTER	20.03.2003

Table 2. Satellite imagery analyzed in this study (gray: two MSS scenes have been merged for 1979)

3.2 Satellite Data Processing

All satellite data has been spatially processed (e.g. rectified and geocoded) to orthophotos by the distributing organization. The spatial quality of all scenes has been checked and the data has been co – registered one scene to each other minimizing spatial errors. Atmospheric corrections have not been applied to either of the scenes. For all scenes the weather conditions have been found ideal at image acquisition, no clouds haze, dust or fog can be detected in the imagery.

3.3 Image Analysis

Image change detection analysis can be performed using different methods. A pixel by pixel change can be applied if two images with the same spatial extend are compared (source xxx). Using satellite data from different sensors makes it more complicated. The imagery has to be analyzed first and in a second step the classification results can be compared (Howarth and Boasson, 1983).

The statistical image analysis approach did not work with the special circumstances of the PHX area; the results were from poor classification accuracy and they could not be used for a valid change detection analysis. A sophisticated object oriented image analysis approach has been applied to the image (Moeller 2004) and led to reliable results in terms of classification accuracy. Following a classification scheme adapted and modified from the NLCD (NLCD, 2005) class

scheme at least 10 classes could be clearly differentiated in each satellite scene (Fig. 2 and 3 see next page).

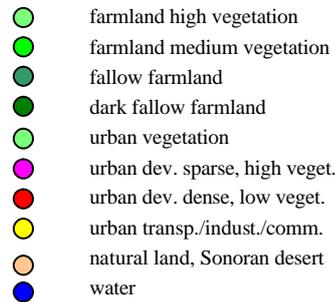


Figure 2. Classification scheme

Focusing on the main urban area, the old flood irrigation areas can be clearly detected. Those are located mainly in the center of the urban area and shown in a magenta color (Fig. 3). These areas belong to older settlements and consist mainly of mesic yards. Newly developed settlement areas with less irrigation can be identified as xeric yards with a red color. The accuracy of this classification for all scenes has been found with 87 %.

4. ANALYSING THE RESULTS

4.1 Up - sampling of the Classification

For the analysis of the changes, a grid pattern with cells each 500 x 500m in size has been created. At least three major land use classes can be found in the PHX area: farmland, urban use and natural land. The underlying dominant class has been up - sampled and assigned to each grid cell in a GIS environment. In a next step the change from a farmland use or natural land cover to an urban use has been calculated for each of the six periods. All of these time steps in a series show the growth of the urban body in an impressive way.

Figure 4 represents the land use in 1973: green areas are under farmland use, beige areas belong to natural lands and rose tones outline urban settlements. The figure also shows all transitions from 1973 through 2003 towards an urban use in light red tones. Grid cells outlined in green indicate a conversion from farmland to an urban use; cells outlined in beige stand for a conversion of natural land towards urban.

4.2 Spatial Analysis

A spatial analysis of the changes has also been performed on the land use changes according to the three major classes. The outcome should answer questions like: where did changes happen and in what distance to the city center did they appear? The 1973 urban body centroid point was found a reliable center point. A wind rose scheme consisting of eight sectors each representing 45 degrees was created and 50 buffer fringes were calculated as well (Fig. 5).

After an overlay of this wind rose scheme over the major land use classes the exact amount of area changed could be calculated for each sector and each fringe. The tabulated data then has been converted to several graphs illustrating the changes as charts (Fig. 6 and 7).

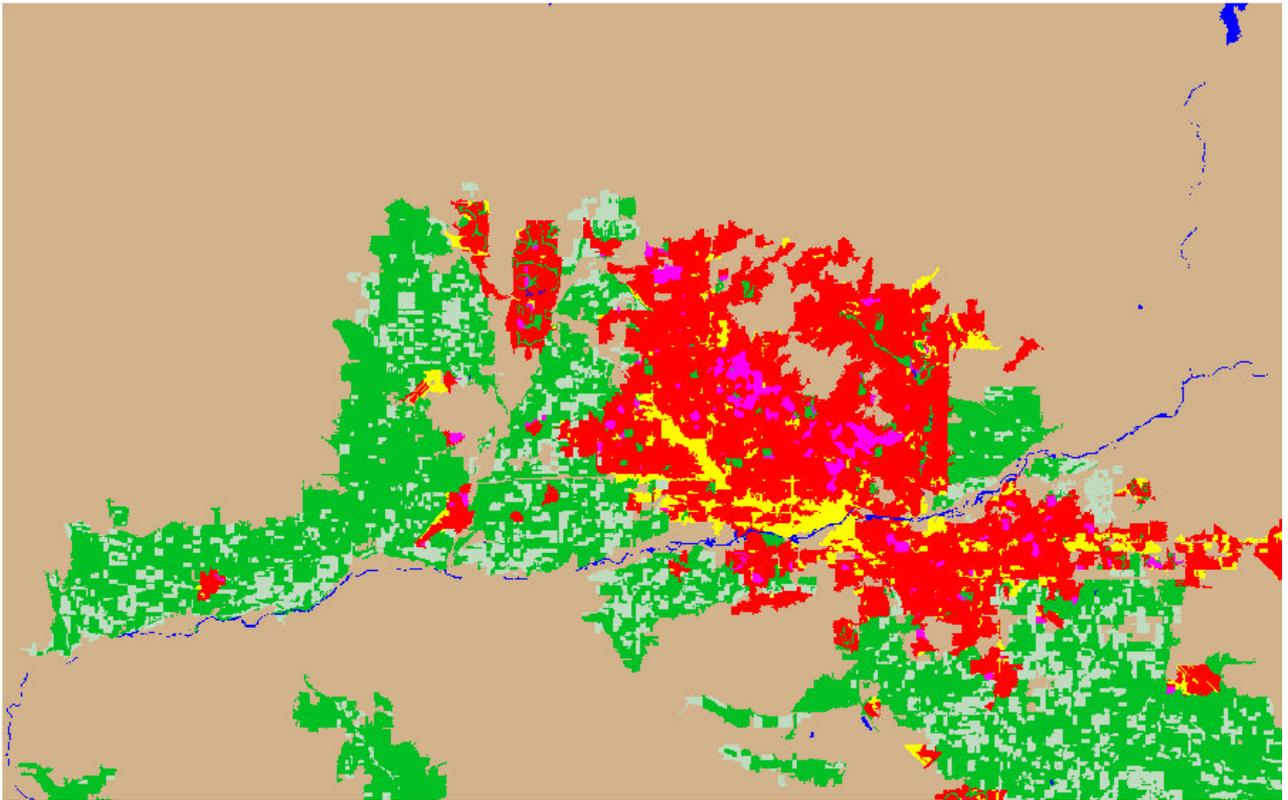


Figure 3. Classification results of the 1985 TM scene

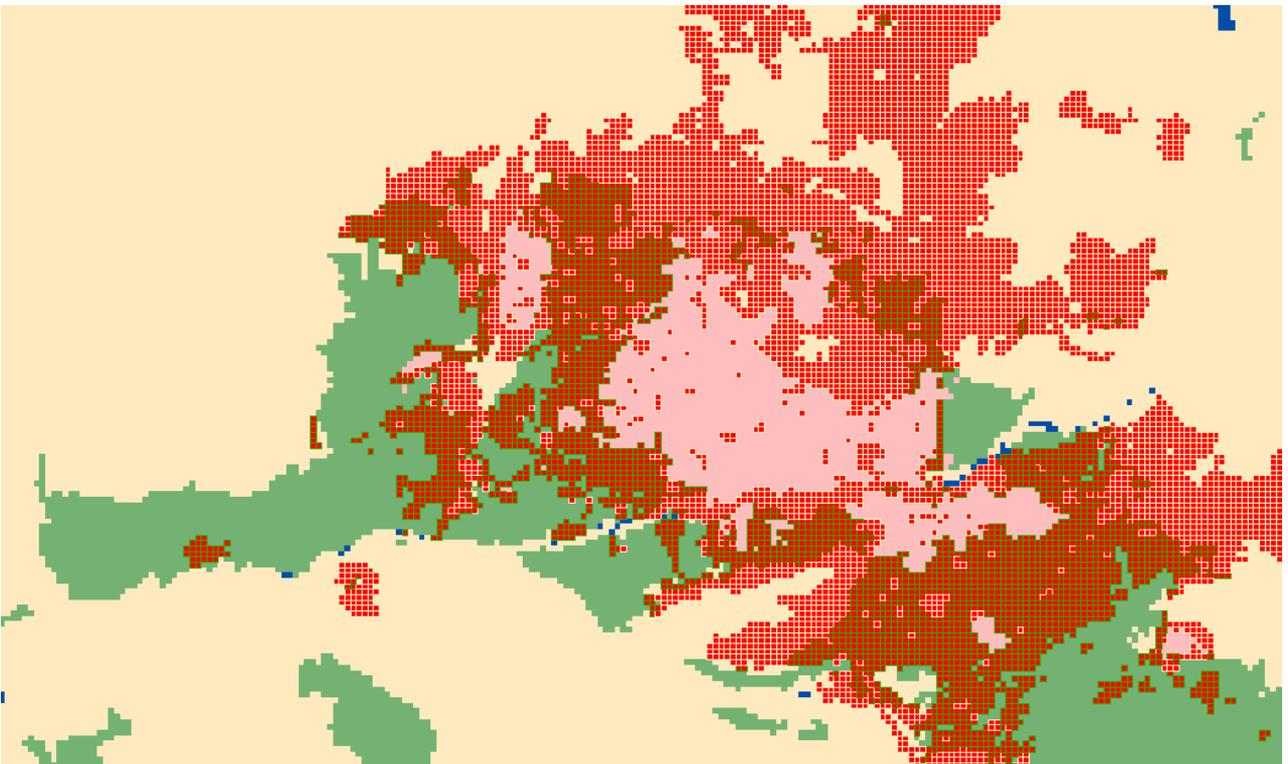


Figure 4. Land Use Changes for the PHX metropolitan area from 1973 – 2003 (Moeller 2004)

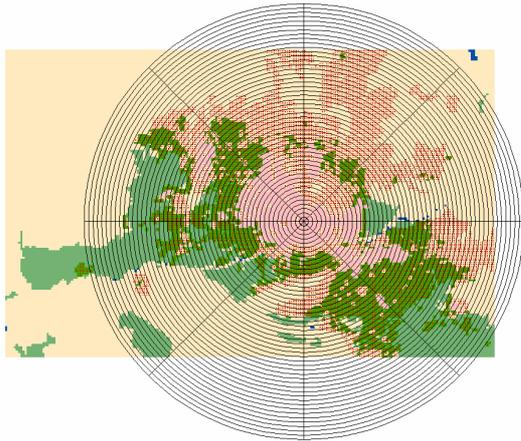


Figure 5. Wind Rose and Buffer Scheme (Moeller 2004)

When interpreting the chart of the wind rose scheme (Fig. 6) the growth for each sector becomes obvious. The main overall growing activity took place in sector one ranging from north to north east. Also the largest and the second largest growth for individual time periods (1991 – 1995, 2000 - 2003) can be recognized for this sector. The second largest growth can be detected for sector three, ranging from east to south east. According to the growth for the time periods sector three consists of the third and fourth largest growing activity between 1991 and 2000.

However the expansion of the urban area is limited for sectors two and five. The reservation of native Apache Indians is bordering in the north east and in the southern part of the aoi the southern mountains, a nature reservation is very close to the urban body.

Figure 7 shows the growth depending on the distance from the 1973 urban centroid. For a better visualization and interpretation five individual fringes have been aggregated to one column. Of course nearly no new development took place close to the 1973 centroid, because it was already under urban usage when this investigation started. It can be detected that the growth follows a specific pattern for the first four periods. The maximum growth for these four periods did take place in the area close to the urban center and it decreases parallel with the distance from the center. This even structure indicates a typical growth in fringes. The later fringe neighbors directly to the fringe of the former period. The trend becomes quite clear when the growth is presented in smoothed curves (Fig. 8).

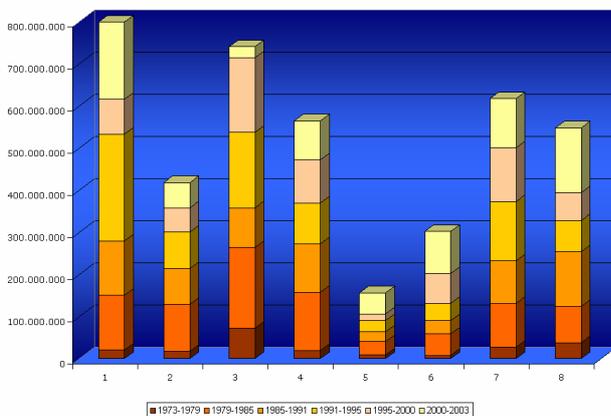


Figure 6. Growth in the Sectors of the Wind Rose Scheme in m² (Moeller 2004)

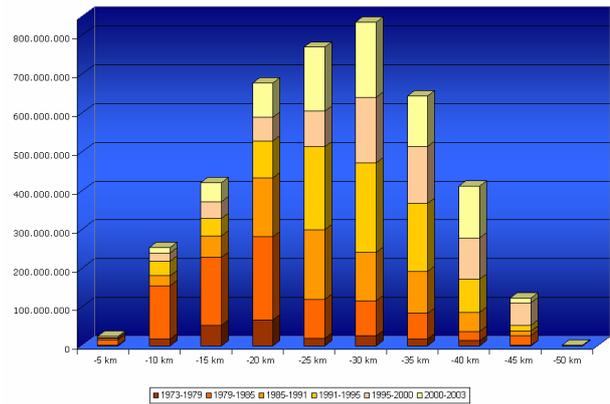


Figure 7. Distance Growth starting at the 1973 Urban Centroid in m² (Moeller 2004)

The development during the last two periods follows a different pattern. Areas with the main growth did not longer move away from the city center. Instead peaks in a distance of approximately 30km can be detected. Considering the main growth during the last period observed took place in the northern sector (Fig. 6) from the main urban region disconnected isolated settlement pattern located in natural land areas is responsible for this curvature.

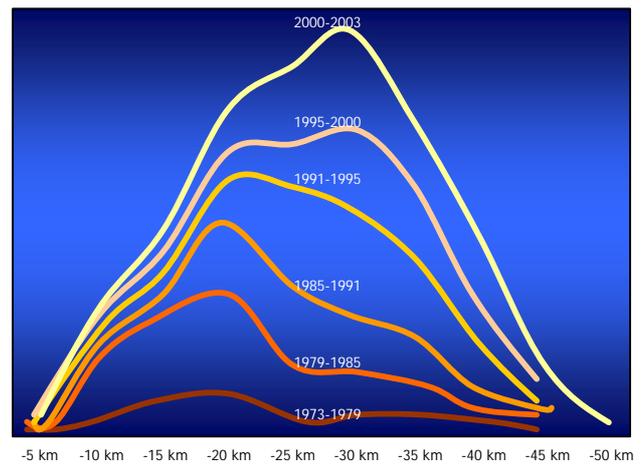


Figure 8. Smooth Curves of the Six Development Periods

5. SUMMARY AND CONCLUSIONS

The analysis of long term remote sensing imagery enabled an in depth monitoring of urban growth pattern. Based on this investigation growth indicators have been developed for a parameterization of the development. In a next step these indicators have to be applied to different urban areas in terms of comparison the different urban growth pattern. This could lead to a valid categorization scheme for urban growth.

ACKNOWLEDGEMENTS

Our thanks go especially to the National Science Foundation (NSF) for funding the AgTrans project. The research for PHX has been carried out mainly under the AgTrans project with some contributions of the NASA funded 100 cities project. Thanks also to Will Stefanov, now with NASA and former ASU colleague, for helping in this research. At least we thank

Markus Heynen, Defines Imaging Germany for supporting this research with an “any where and free” dongle of the eCognition software.

REFERENCES

- Asterweb. <http://asterweb.jpl.nasa.gov/> (accessed 21 Jan 2005)
- Aviris. <http://aviris.jpl.nasa.gov/> (accessed 20 January 2005)
- CHRIS. <http://www.chris-proba.org.uk/frames/index2.html> (accessed 24 Jan 2005)
- EOS Webster. <http://eos-webster.sr.unh.edu/home.jsp> (accessed 11 Febr. 2005)
- ESDI Earth Science Data Interface. <http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp> (accessed 14 Febr. 2005)
- Henderson, F. M. 1982. An Evaluation of Seasat SAR Imagery for Urban Analysis. In: *Remote Sensing of Environment*, Vol. 12, pp. 439-461.
- Howarth, P. J. and E. Boasson 1983. Landsat Digital Enhancements for Change Detection. in Urban Environments. In: *Remote Sensing of Environment*, Vol. 13, pp. 149-160.
- Hyperion. <http://eo1.gsfc.nasa.gov/Technology/Hyperion.html> (accessed 20 Jan. 2005)
- Landsat. <http://www.landsat.org> (accessed 11 Febr. 2005)
- LLCD. <http://www.mrlc.gov/index.asp> (accessed 14 Febr. 2005)
- Moeller, M., 2004. Monitoring Long Term Transition Processes of a Metropolitan Area with Remote Sensing. In: *Proceeding of the IGARRS 2004 IEEE International Geoscience and Remote Sensing Symposium*, Anchorage, AK, pp. 3398-3401.
- Neer, J. T., 1999. High Resolution Imaging from Space - A Commercial Perspective on a Changing Landscape. *International Archives of Photogrammetry and Remote Sensing*, XXXII (7C2): pp. 132-143.
- Sabins, F. F., 1996. Remote sensing: principles and interpretation. New York, NY, W. H. Freeman.
- TRFIC Tropical Rain Forest Information Center, 2004. <http://www.globalchange.msu.edu/trfic/> (accessed 20 Jan. 2005)
- United Nations, 2002. *World Urbanization Prospects The 2001 revision Data Tables and Highlights*. ESA/P/WP.173. <http://www.un.org/esa/population/publications/wup2001/wup2001dh.pdf> (accessed 20 Jan. 2005)
- USGS. <http://www.usgs.gov/pubprod/satellitedata.html> (accessed 14 Febr. 2005)