Presented at the Nordic GIS Conference, Helsinki, 8-10 October 2001.

Change detection of urban areas using multitemporal Landsat TM satellite data in Turku, Finland

Filip Hartvich, Keijo Koskinen & Petri Pellikka
University of Turku, Department of Geography
20014 TURKU, Finland
e-mail: typ@post.cz, ketako@utu.fi, petri.pellikka@utu.fi

1. Introduction

The land use of the City of Turku has developed strongly during the past decades. For a healthy continuation of the development it is important to examine the type of land use changes and their location. It is obvious that some land use activities (harbour, industry, housing etc.) expand while other land use activities (agriculture, forestry) have to withdraw.

Remote sensing data are a powerful tool to make quick land use assessments. Change detection analysis is enabled by multitemporal data set, but in order to reliably and quantitatively study the changes it is necessary to calibrate the data geometrically and spectrally. With the GIS tools provided by image processing and geoinformatics softwares the processing of the data and spatial analysis are nowadays a cost-effective method.

This study has two objectives. The first is to compare two methods for normalizing the brightness variations of two satellite images used in order to enable change detection analysis. The first method is histogram matching tool provided by Erdas Imagine and the second is multitemporal relative spectal calibration algorithm (Pellikka 1998). Second objective is to detect land use changes in urban and suburban areas of the northwestern parts of Turku between 1984 and 1997. The results can be used to show how the city planning has succeeded. The results may also give new aspects for the planning process in the future.

We present calibration methods for multitemporal relative spectral calibration of the two Landsat TM images used for the analysis, show the results resulting from the digital supervised classification of the two images and discuss briefly the causes for the changes detected.

2. Study area and data

The city of Turku is located in southwestern Finland on the coast of Baltic Sea. Turku is the oldest city and a provincial capitol. With approximately 170 000 inhabitants it is a fifth large city of the country. However, combining the population of the neighbouring towns and communities, which belong to the same market area, the total population is about 250 000, which makes the area third largest urban agglomeration in Finland. During the past years the urban land-use, such as commercial areas, industry, roads and sub-urban housing, has been gaining land from agriculture and forestry.

Our study concentrates on a rectangular area from southwest to northwest between the cities of Turku and Raisio most of the area belonging to Turku. The size of the study area is 5 by 12 km. The southern part of the area is on the park landscape of Ruissalo Island and the northern part reaches the sub-urban areas of Jäkärlä. The geographical location of the area is shown in Figure 1.

The city centre of Turku is located in the southeast part of the area, while the southwest part belongs mainly to the City of Raisio. The area between both city centres is densely populated with a reduction of density from southeast to northwest. At the middle of our area there is the airport of Turku. The prevailing land use type northeast from the airport is agriculture.

The study concentrates on the changes taken place between 1984 and 1997 due to the dates of the satellite images used. The images were acquired on 2nd of June 1984 and 9th of August 1997. 13 years time difference in rural areas would not give any significant changes in land use, but in an urban fast-developing area the time span is considered to be long enough. The satellite data is acquired by Landsat TM (thematic mapper) sensor, which detects the earth from the altitude of 705 km with seven spectral bands from blue to thermal infrared wavelength regions. The spatial resolution of the data is 30 meters, expect in the thermal band, which has a resolution of 120 meters. The 30-meter resolution is considered to be still roughly feasible for remote sensing of urban areas. The proportion of the satellite images used is shown in Figure 1.

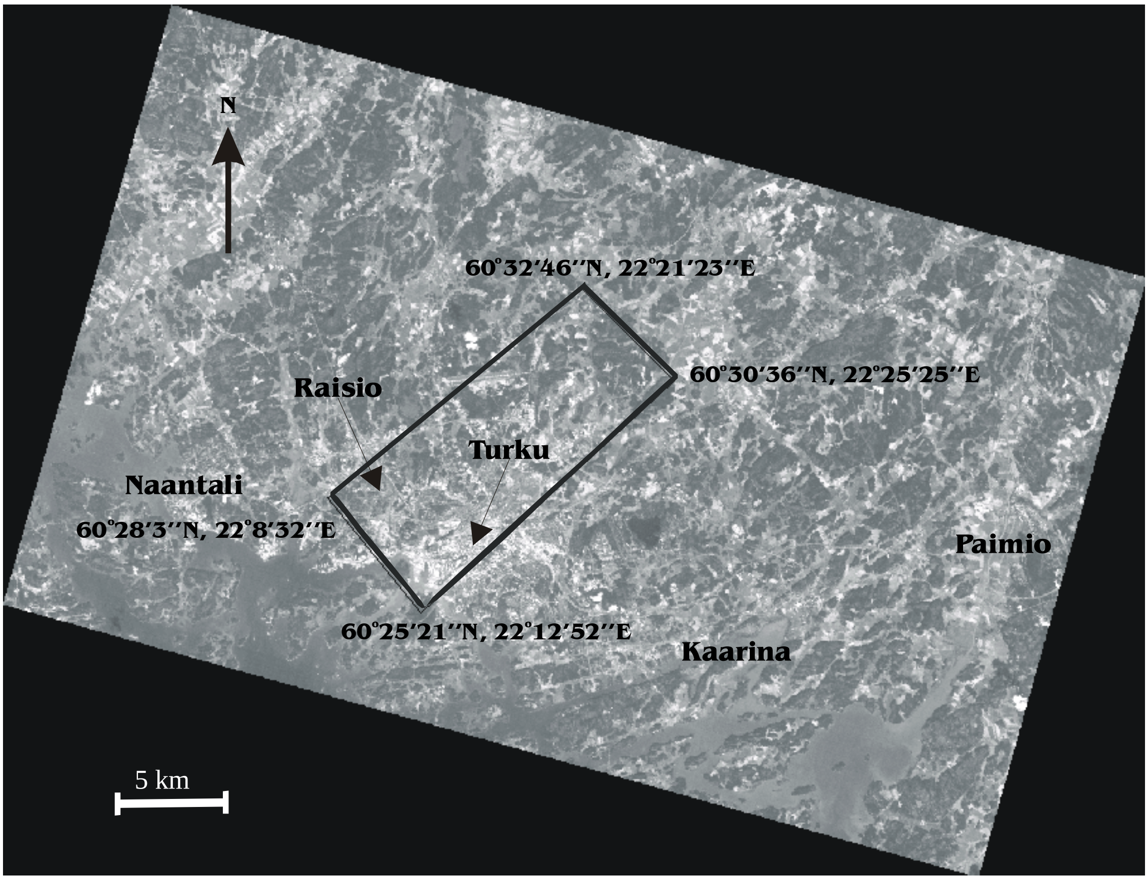


Figure 1. 1997 satellite image and the coordinates of the study area.

The difference between the dates of the images used causes phenological differences for the vegetation, and especially for the cultivated crops, which causes difficulties in the comparison of the land use. Between June and August, significant changes occur in the fields caused mostly by harvesting the grasslands and crops. These phenological differences evidently cause misclassification mainly between fields, open land and built-up areas. Other factors causing difficulties in the image interpretation are the seasonal changes in sun-angles and differences in atmospheric characteristics. These factors may also cause misclassification and are evidently hampering digital analysis of the data. They are to be corrected for.

Digital base maps in a scale of 1:20000 from different years were used for the rectification of the data into Finnish coordinate system (KKJ2) and as layers for the change detection analysis in ArcView. Paper maps in scale 1:20000 were used for the change detection analysis and for orienteering in the field.

3. Methods

The image processing included rectification, multitemporal relative spectral calibration applying two different methods, unsupervised classification and supervised classification for both TM images. Most of the image processing activities were conducted by Erdas Imagine, but ER_Mapper was used for the radiometric enhancement. ArcView was used for the visualisation of the results.

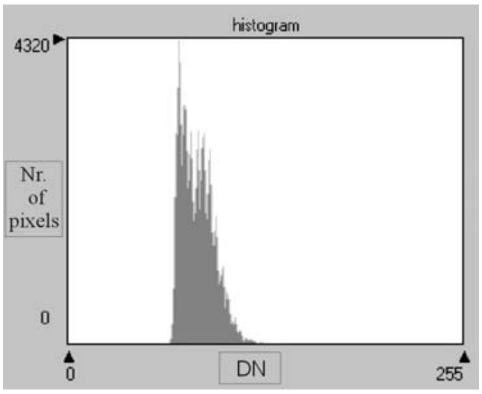
3.1. Rectification

Rectification of the images was compulsory for three reasons. Firstly, the training areas for the classification were to be collected by GPS and were to be then located from a rectified image. Secondly, rectification is needed in order to use the classification results as layers for GIS analysis. Thirdly, for reliable change detection analysis, the two images had to be co-registered. The Landsat TM image from 1997 was rectified first using a map mosaic constructed from digital base maps of Finland. After rectification, the 1984 image was co-registered with 1997 image.

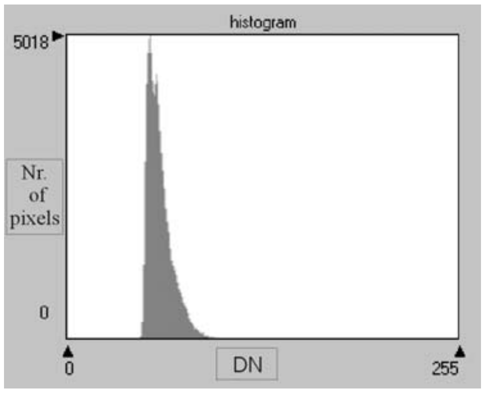
3.2. Multitemporal relative spectral calibration

In order to objectively analyse the reflectance characteristics of the land surface registered as digital numbers (0-255), a relative spectral calibration was performed for the data (Pellikka 1998). The calibration removes the disturbing effects on the image radiometry caused by differences in atmospheric scattering during the data acquisition and solar angles. After the calibration, the digital numbers of the two images are comparable. The calibration is relative, and do not convert the DN values to absolute reflectance values as radiative transfer codes, such as Lowtran 7 (Kneizys et al. 1988) or 6S do (Vermote et al. 1997).

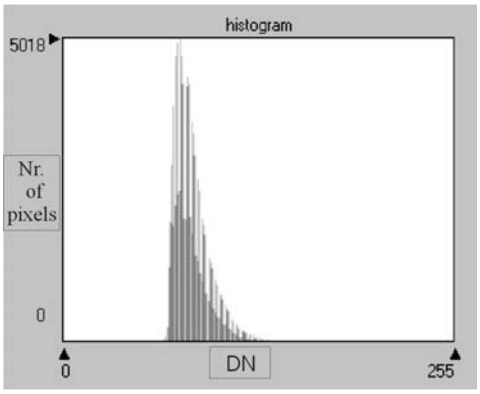
Two methods were applied. The first was histogram matching tool provided by Erdas Imagine. Since the software performs the calibration automatically, it is not known what kind of syntax is used for it. The prerequisites of using histogram matching are that the general shape of the histogram curves of the images are similar, relative dark and light features in the images should be the same and spatial resolution should be the same (Erdas 1997). Since the Landsat TM images were covering the same land surface and both images were taken in summer, it was assumed that these three conditions were fulfilled. For the calibration, histogram matching uses the whole image area as a reference area. The histograms of the two images are shown in Figure 2.



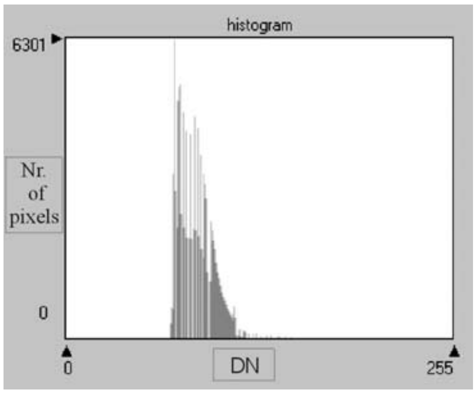
A



B



C



D

Figure 2. Histograms of the satellite images band 1 (blue): A) original 1984 image (master), B) original 1997 image (servant), C) 1997 calibrated image by Pellika's method.and D) calibrated image by Histogram matching.

The second method (MRSC) is based on derivation of the calibration function from reflectance differences of selected bright and dark reference areas in both images (Pellikka 1998). Assuming a linear sensor output, dark and bright reference areas are selected from the two satellite images, and the mean and standard deviations of the DNs are derived. That image in which the dynamic range of the reference areas is greater is chosen as a master image and the image having lower dynamic range is chosen as a servant image (Table 1). In our case, the 1984 TM image was chosen as a master, since its dynamic range was greater in every wavelength band. In other words, the spectral characteristics of the servant image are made comparable with the one of the master image by stretching the dynamic range.

Table 1. The DN values of the reference areas before the calibration and after the calibration applying the two different methods. The dynamic range is greater with the 1984 image. After the calibration using two methods, the difference in DN values between the bright and dark reference areas is less when using the MRSC.

	Original 1984 image (master)			Original 1997 image (servant)			Calibrated 1997 image Histogram matching, based on Erdas Imagine				Calibrated 1997 image Multitemporal relative spectral calibration, based on Pellikka 1998			
BAND	Bright area	Dark Area	Dynamic range	Bright Area	Dark area	Dynamic range	Bright area	Diff. in DN	Dark area	Diff. in DN	Bright area	Diff. in DN	Dark area	Diff. in DN
Band 1, Blue	112	69	43	80	49	31	121	+9	70	+1	109	-3	69	0
Band 2, Green	49	23	26	35	16	19	52	+3	25	+2	47	-2	23	0
Band 3, Red	54	18	36	40	12	28	54	0	20	+2	53	-1	18	0
Band 4, NIR	51	13	38	37	10	27	46	-5	17	+4	49	-2	13	0
Band 5, MIR	68	6	62	48	6	42	58	-10	13	+7	67	-1	6	0
Band 6, TIR	130	111	19	144	126	18	135	+5	112	+1	124	-6	111	0
Band 7, MIR	43	4	39	27	3	24	37	-6	7	+3	41	-2	3	-1

The bright and the dark reference areas are selected visually from the images. In our case, as a dark reference area a lake surface (Littoistenjärvi) was used due to the high absorbance of radiation by water surfaces (Lillesand & Kiefer 1994). An area in the city centre of Turku was used as a bright reference area due to its high reflectance and because it was a large **yhtenäinen** area. The values of the brightest and darkest area are entered to the user-defined syntax in Erdas Imagine Model Maker (Figure 3) and the software calibrates the servant image's spectral characteristics comparable to the spectral characteristics of the master image.

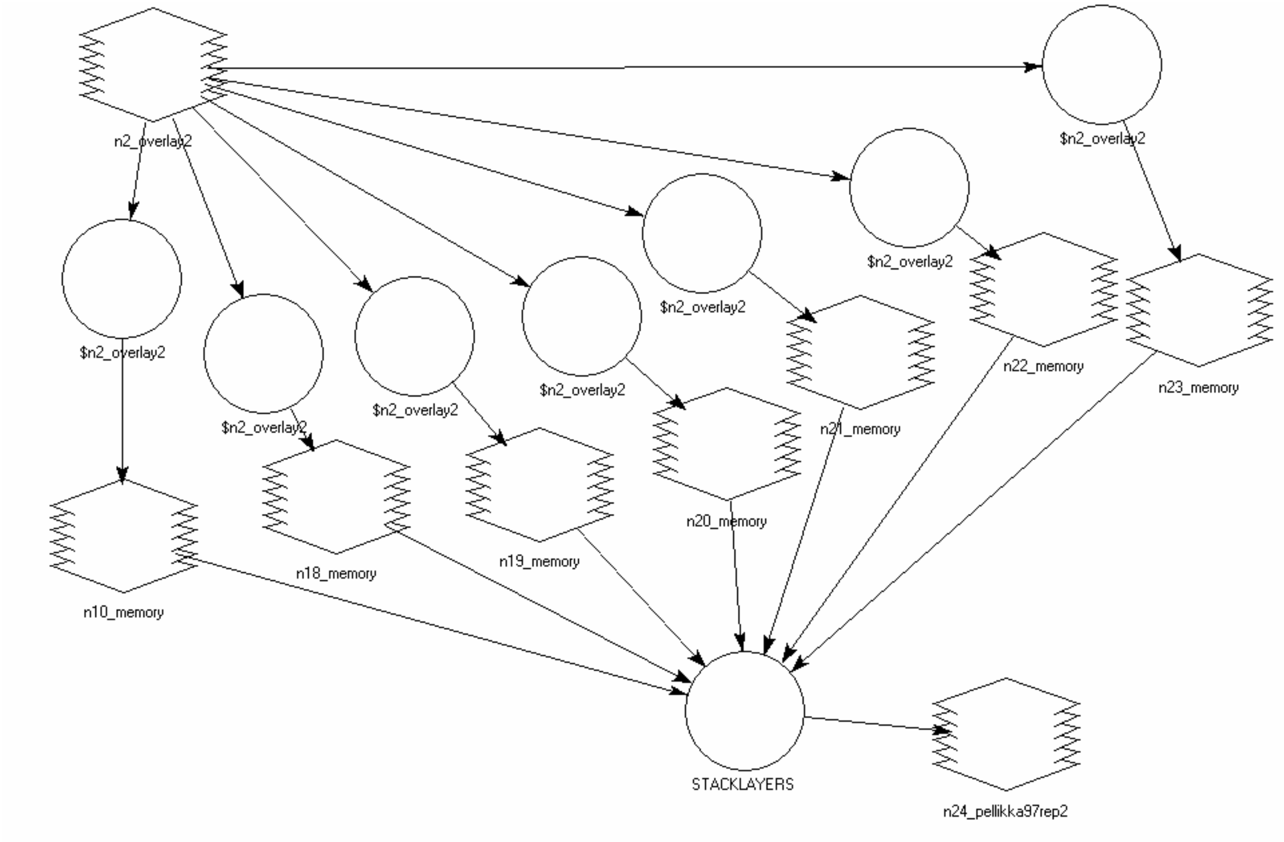


Figure 3. Model Maker in Erdas Imagine.

The syntax consists of three equations. The linear regression function for the servant image is determined by defining the coefficient as (Eq. 1).

$$c = (x_{MD} - x_{MB}) / (x_{SD} - x_{SB}) \quad \text{Eq. 1}$$

Where c = coefficient
X_{SD} = mean of the dark reference image in the servant image
X_{SB} = mean of the bright reference image in the servant image
X_{MD} = mean of the dark reference area of the in the master image
X_{MB} = mean of the bright reference area in the master image

And intercept as (Eq. 2):

$$i = c \bullet X_{SD} - X_{MD} \quad \text{Eq. 2}$$

Where i is intercept.

The new DN values (DN* in the equation) for the servant image are calculated by Eq. 3.

$$DN^* = DN \bullet c - i \qquad \textit{Eq. 3}$$

As a result, the means of the reference areas in each data set were the same, and the standard deviations were also closer to each other that before the calibration.

3.3 Classification

Unsupervised classification was used first to obtain an overview of the spectral differences of the area. The classification result was also used for defining the training areas for the supervised classification. The TM images were classified in 30 classes and afterward classes of similar land use type were merged. In total, 27 training areas were detected with the help of GPS in the field. Three training areas for a water class were selected from a map. A region growth command of Erdas Imagine was used for expanding the training area from single coordinate point recorded by GPS.

As a result we got six different land use classes: dense settlement, scattered settlement, park and green city area, fields, forest and water. Dense settlement means mainly city centres and areas, which are built entirely of concrete and asphalt. Residential areas where lawns and sand are found between the houses belong to the scattered settlement area. Park and green city areas contain parks, small forests and larger single-family residential areas. The fields are agricultural fields cultivated by hay, cereals or other kind of crops. The crop species were not specified. The forest class is predominately coniferous forest, while the deciduous forest belongs to park and green city areas. Water class is lakes or sea. A maximum likelihood classification algorithm was used for the supervised classification.

The land use changes were visualised by the creation of difference image. The difference image was created by **vähentämällä** the supervised 1984 image from the supervised 1997 image (Figure 4). It does not show which land use class has changed to another, but it only shows the areas where some kind of land use change has occurred. For the analysis of the land use change the difference image was overlaid with digital basic maps.

4. Results

After the multitemporal relative spectral calibration using both methods the spectral characteristics of the images became comparable. The histogram matching resulted in slight overcorrection in each band with the dark reference areas (Table 1). With the bright reference area, an overcorrection took place with blue, green and thermal infrared bands, while the middle infrared bands and NIR band were undercorrected. Only the red band matched perfectly. MRSC resulted in very small undercorrection with the bright reference areas and almost perfect match with the dark reference areas. In general, the calibration of the dark areas succeeded better than the calibration of the bright reference areas with both methods. Table 4 shows the impact of both corrections on the image spectral characteristics.

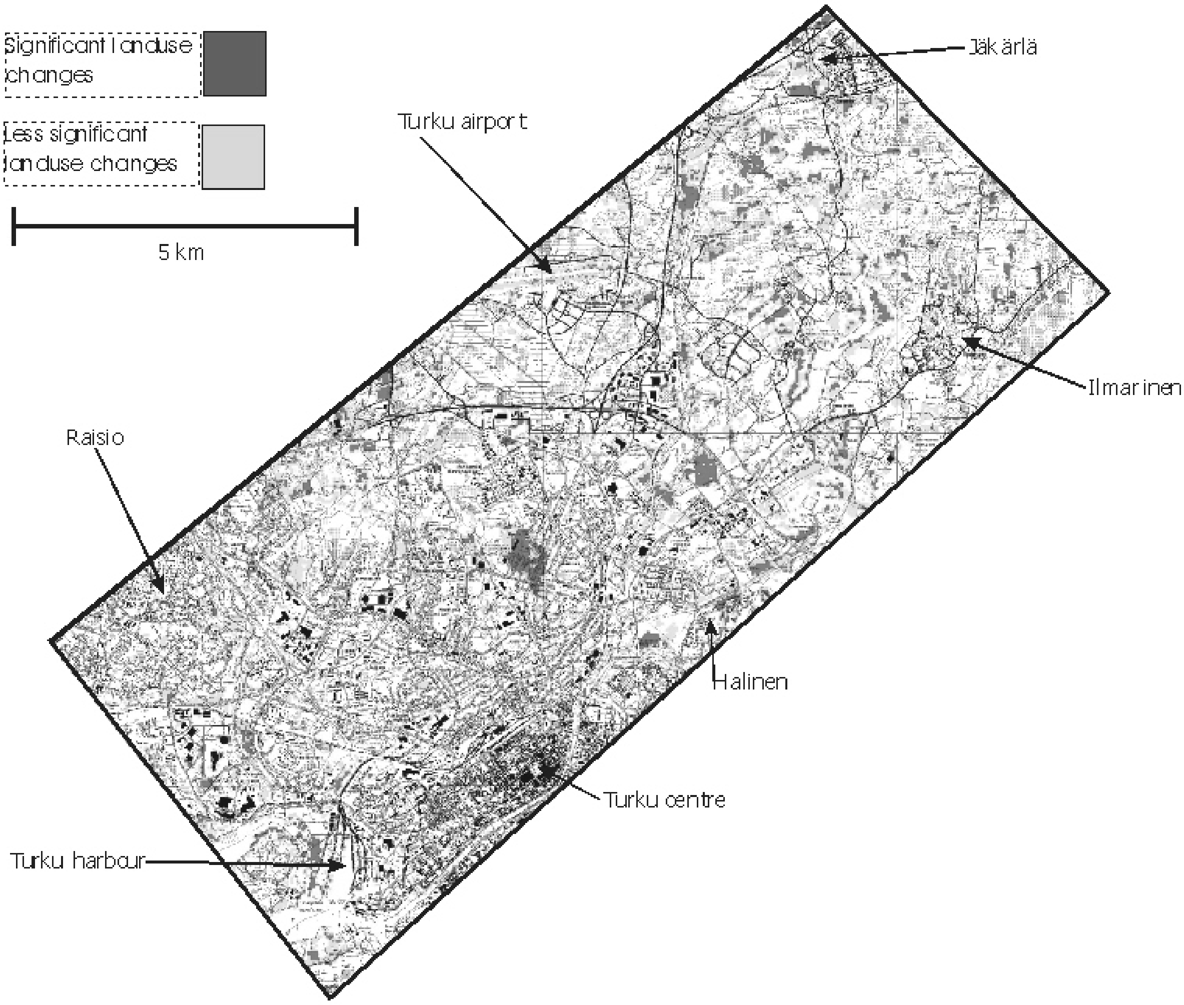


Figure 4. Difference image

Table 4. Standard deviations and means of the satellite images study area before and after correction using both methods.

		Original 1984 image (master)	Original 1997 image (servant)	Calibrated 1997 image by histogram match	Calibrated 1997 image by Pellika's method
Band 1, Blue	Standard deviation	12,786	9,580	16,529	13,096
	Mean	83,441	59,717	86,613	83,725
Band 2, Green	Standard deviation	7,657	5,711	9,216	7,689
	Mean	34,154	24,335	35,294	34,163
Band 3, Red	Standard deviation	10,946	8,632	11,917	11,110
	Mean	35,590	24,322	34,701	33,569
Band 4, NIR	Standard deviation	15,426	13,743	12,352	19,043
	Mean	56,760	48,328	55,506	65,450
Band 5, MIR	Standard deviation	18,755	15,740	15,407	23,249
	Mean	58,066	48,173	57,458	67,932
Band 6, TIR	Standard deviation	4,882	4,888	5,095	4,888
	Mean	125,547	135,363	128,146	120,363
Band 7, MIR	Standard deviation	12,006	8,408	10,864	13,855
	Mean	27,433	19,514	27,811	30,381

The classified images are presented in Figure 5. The classification results were analysed by visual analysis, but also by visiting the field and checking the results. No thorough land cover classification assessment were done. The greatest misclassifications occurred between built-up areas and field depending on the phenology of the fields. If the fields were ploughed or harvested, they were typically misclassified as built-up areas. The supervised classification and visualisation showed that most significant changes were the growth of built-up areas. Simultaneously, the area of forests and fields has decreased due to construction of roads and new suburban areas.

The difference image (Figure 4) shows that greatest differences in land use have occurred in the areas of Halinen, Kärsämäki, Impivaara and in the harbour of Turku. The changes in the northern parts of the study area are also strong, but are presumable caused by the phonological differences of the agricultural fields between June and August. The changes depicted in the difference image are considered to be real in Halinen, Kärsämäki, Impivaara and in the harbour. In Halinen, during the last decade a new sub-urban housing area with detached houses and blockhouses has been constructed. Kärsämäki is a strongly expanding industrial area. The settlements in Impivaara are becoming denser, since new houses are built in large lots. In addition, two new ice rinks, a football hall and parking lots for these facilities have been built between 1984 and 1997. These changes have decreased the forest and park landscape of the area. The changes in the harbour are difficult to explain. It has been growing, but not as strongly as the change intensity shows. The changes may be related to different land use practises within the harbour.

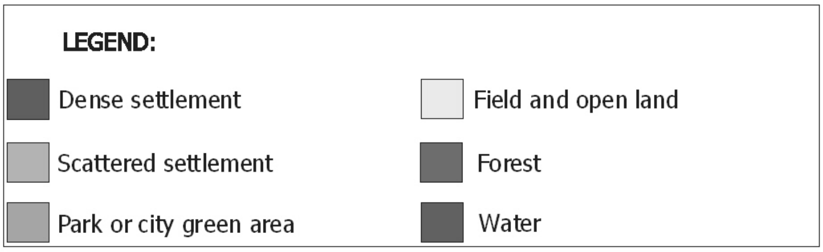
5. Discussion

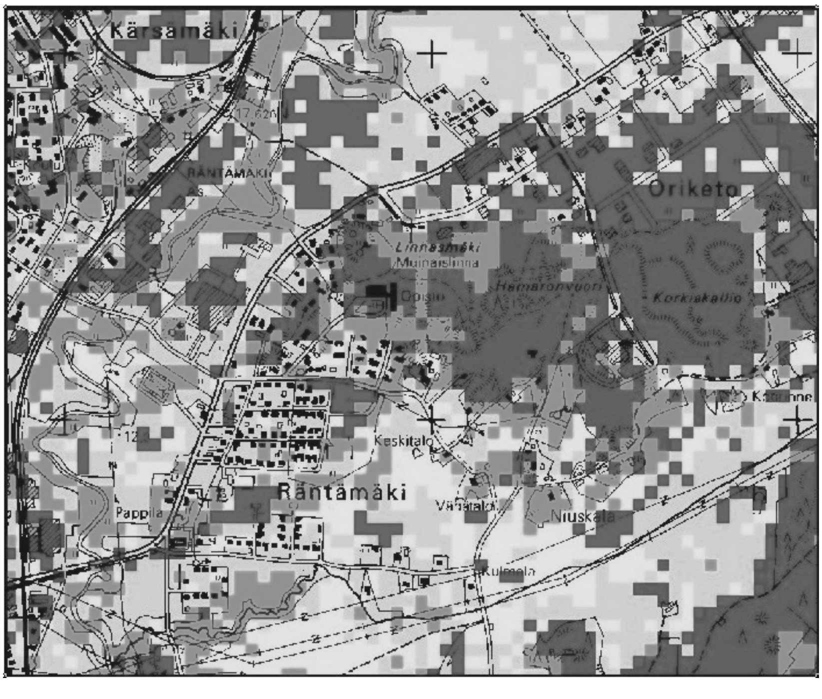
The calibration methods applied were simple, increased the data quality and allowed change detection using satellite data from different data acquisition dates. The methodology can be easily applied in any area of the world from which remote sensing data exist and any kind of change detection is of interest.

The multitemporal spectral calibration (MRSC) resulted in better match between the reference areas, but it is considered more time consuming process than histogram matching. The absolute differences of the results compared to the histogram matching tool were not significant so it should be estimated how accurate results the user needs, and how much time the user can invest to the calibration. However, because of the restrictions of the histogram matching, the MRSC may be the only possibility if the images were taken from different seasons.

In developed countries in which cadastral services and mapping are well conducted, such remote sensing methods for land use changes may not be necessary. The methods presented here are therefore considered to be more useful for remote sensing of urban areas and land cover changes in developing countries.

A.





B.

Figure 5. Supervised classified images: A) 1997 image and B) 1984 image.

6. References

Erdas (1997). *ERDAS Field Guide*, 4th edition, revised and expanded. ERDAS ®, Inc., Atlanta, 656 p.

Kneizys, F.X., G.P. Anderson, E.P. Shettle, W.O. Gallery, L.W. Abreu, J.E.A. Selby, J.H. Shetwynd & S.A. Clough (1988).*User's Guide to LOWTRAN-7.* Environmental Research Paper 1010, AFGL-TR-88-0177, Air Force Geophysics Laboratory, Hancom AFB, 137 p.

Pellikka, P. (1996). Multitemporal relative spectral calibration of airborne video camera data. In *Proc. of 2nd International Airborne Remote Sensing Conference and Exhibition*, 24-27 June 1996, San Francisco, USA, Vol. III, 17-25.

Pellikka, P. (1998). Development of a correction chain for multispectral airborne video camera data for natural resource assessment. *Fennia* 176:1, 1-110.

Vermote, E.F., D. Tanré, J.L. Deuzé, M. Herman & J-J. Morcrette (1997). Second simulation of the satellite signal in the solar spectrum, 6S: an overview. *IEEE Transactions on Geoscience and Remote Sensing* 35, 675-686.