RADIOMETRIC CORRECTION OF MULTITEMPORAL LANDSAT TM DATA FOR DETECTING RAPID CHANGES IN MINERAL SOIL FOREST LAND

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ABSTRACT

Possibilities to produce generic training data for forest change detection were studied applying linear radiometric calibration combined with studentization. The standwise approach with Landsat TM image pairs was applied and the spectral features used, were the difference of stand mean and standard deviation. The timing of several forest treatments within a three-year image interpretation interval did not affect to the spectral separability of the treatments. After the regression calibration and studentization all the treatment classes were significally separable at least on one difference channel. The possibilities of composing generic training data where training observations need not come be from the image pair analysed was demonstrated. After regression calibration and studentization the spectral responses were quite similar on all image pairs except on TM channel four.

1. INTRODUCTION

Detecting changes in forest canopy is important from strategic to operational management planning of nature resources. For operational purposes, forest change detection is necessary for controlling the quality of the information used in forest management because of possible updating errors in continuously updated data bases, and for detecting forest damages large enough to affect management decisions. For smaller scale, updating is needed for detecting trends such as defoliation, for controlling forest activities over large areas such as the European Union and for detecting natural disasters in remote areas. Satellite remote sensing provides an economical and repetitive source of information for change detection purposes if specific changes can be detected based on their spectral response.

Before detecting changes different pre-processing methods for producing multitemporal satellite images have been proposed. Normally the satellite acquisitions are first registered together and rectified to some map coordinate system. After these different radiometric calibrations have been proposed to make image acquisitions radiometrically comparable (e.g. Singh 1989). However, only few methods have been accurate enough for detecting changes such as silvicultural activities or forest damages in the Boreal Forest conditions. When absolute and relative calibration methods have been compared the absolute calibration has not been accurate enough, and relative methods have been proposed (Olsson 1994). Selection of the actual radiometric calibration method depends on the ground truth available. If there is no ground truth available, methods such as histogram matching have been proposed, but if for example forest/nonforest delineation or forest stand delineation is available, good results have been obtained by linear regression calibration (Olsson 1993, 1994 Varjo 1996). In the case of a single image pair the need for radiometric calibration has not been very clear. Häme (1991) has shown better forest change detection results without calibration but Varjo and Folving (1996) have found that calibration improves change clustering results notably. In the case of several image pairs, such as in operational updating or control of forest management information, radiometric calibration seems necessary. If supervised methods are used it cannot be expected that training data for change detection is collected separately for every image pair (Varjo 1996). For producing generic training data good results have been obtained by combining linear regression calibration and studentization (Olsson 1994).

In this work, relative radiometric calibration methods are studied for producing multitemporal data for detecting rapid changes in forest canopy at a scale of 1:20 000. Forest stands originating from base line field inventory are used as observation units (Varjo 1996). The combination of relative radiometric calibration and studentization methods (Olsson 1994) for detecting changes as small as possible from Landsat a TM difference images is proposed for supervised change detection methods. The use of relative calibration is studied for producing generic radiometrically comparable training data for several image pairs covering the same geographic location and for image pairs covering different geographic locations of a similar forest ecosystem type. The interval within Landsat TM image pairs vary from one to three years. There are two test sites available for the boreal forest zone in Finland. The spectral response due to different forest management treatments is analysed.

2. MATERIAL AND METHODS

The test site was located in Hyrynsalmi, referred H, in Eastern Finland (centre Long. 28°30' E, Lat. 64°30'N). The forest in the study area is typical Boreal Forest dominated by coniferous species (*Pinus sylvestris* and *Picea abies*). An operational forest stand map based on aerial photo interpretation was combined with multitemporal images, and these forest stands were applied as observation units. Only mineral soil stands were used in this work. The untreated observations totalling 390 stands were used in calibration and the change analyses was based on all observations totalling 496 stands (Table 1). The mean area of a stand was 6.0 ha.

Table 1. Number of observations in Hyrynsalmi data.

Name	Obs.	Description
Untreated (Unt)	390	only normal growth exist
Uncommercial thinning (Unc. Thinn.)	13	clearing or thinning of young stand
Commercial thinning (C.thinn)	15	about 30% of basal area is removed
Preparatory cut (Prep cut)	26	thinning of mature stand
Regeneration cut (Reg.cut)	13	only seed trees remain
Clear cut	28	all trees removed
Soil preparation (Soil prep.)	11	harrowing for regeneration

There were three Landsat TM images available for the study area. In addition two acquisition from Varjo's (1996) study were used (Table 2). The details of the Nurmes data, referred N, used for comparing image pairs form different locations are presented by Varjo (1996).

Table 2. Landsat TM images used, H=hyrynsalmi data, N=nurmes data.

Date	Track	Row
H 21.06.1990	188	15
H 10.06.1992	188	15
H 31.07.1993	188	15
N 08.06.1988*	187	15
N 23.06.1990*	186	15

*From Varjo's (1996) study

Robust regression was used to make an earlier image radiometrically comparable with a later one within one image pair. Regression coefficients between stand means were estimated using unmanaged forest stands. For Landsat TM channels 3,4 and 6 multiple regression was used (Equations 1,2 and 3) and for other channels simple regression was selected (Equation 4). For the image pair 187,186/15 band to band regression, such as in equation 4, was used for all the TM channels (Varjo 1996).

$$\overline{y}^{t}_{ch3}(n) = \beta^{n}_{0} + \beta^{n}_{1}\overline{x}^{t-n}_{ch3} + \beta^{n}_{2}\overline{x}^{t-n}_{ch4} + \varepsilon \qquad (1)$$

$$\overline{y}^{t}_{ch4}(n) = \beta^{n}_{0} + \beta^{n}_{1}\overline{x}^{t-n}_{ch4} + \beta^{n}_{2}\overline{x}^{t-n}_{ch3} + \varepsilon \qquad (2)$$

$$\overline{y}^{t}_{ch6}(n) = \beta^{n}_{0} + \beta^{n}_{1}\overline{x}^{t-n}_{ch6} + \beta^{n}_{2}\overline{x}^{t-n}_{ch4} + \varepsilon \qquad (3)$$

$$\overline{y}^{t}_{ch(i)}(n) = \beta^{n}_{0} + \beta^{n}_{1}\overline{x}^{t-n}_{ch(i)} + \varepsilon \qquad (4)$$

β_p = parameters, $p \in \{0,1,2\}$

$\overline{y}^{t}_{ch(i)}$ = mean intensity of a stand on channel i at the moment t

$\overline{x}^{t-n}_{ch(i)}$ = mean intensity of a stand on channel $i \in \{1,2,5,7\}$ at the moment t-n

n = interval between image acquisitions $n \in \{1,2,3\}$

ε = error term.

The inverse of within stand variance on the independent channel of the earlier image was used as weight in parameter estimation. The calibration parameters were estimated twice. After the first estimation the outliers and leverage points were detected and excluded from calibration and the final parameters were estimated without those observations (Varjo 1996). An observation was considered to be an outlier if the difference of the residual from zero was statistically significant according T-test at 5% risk. Similarly, an observation was considered to be a leverage point if the Cook's distance was greater than 1 (Rousseew & Leroy 1986, Varjo 1996).

After calibration, the differences of stand means (Equation 5) and standard deviations (Equation 6) were formed for each channel between the calibrated earlier image and the original later image.

$$\Delta M_{dn(i)} = \overline{y}^{t}_{i} - \hat{\overline{y}}^{t-n}_{i} \qquad (5)$$

$$\Delta SD_{dn(i)} = SDy^{t}_{i} - SD\,\hat{y}^{t-n}_{i} \qquad (6)$$

$\Delta M_{dn(i)}$ = difference of stand intensity means expressed in dn on channel i

$\Delta Sd_{dn(i)}$ = difference of within stand standard deviation expressed in dn on channel i

$\overline{y}^{t}_{i}$ = original stand mean intensity on channel i at the moment t

$\hat{\overline{y}}^{t-n}_{i}$ = stand mean intensity on channel i at the moment t-n calibrated to the intensity level of moment t

SDy^{t}_{i} = standard deviation of stand intensities on channel i at the moment t

$SD\,\hat{y}^{t-n}_{i}$ = standard deviation of stand intensities on channel i at the moment t-n calibrated to the intensity level of moment t.

Because of regression calibration the intensities in both dependent and independent images were scaled to the level of independent image. When more generic training data was considered, the regression calibrated difference observations were studentized (in the sense of Weisberg 1985) according to the leverage and regression error (equation 7) (e.g. Olsson 1994).

$$\Delta X_i = \frac{\Delta X_{dn(i)}}{RMSE_i \sqrt{1 + lev_x}} \qquad (7)$$

ΔX_i = studentized difference of $X \in \{\Delta M, \Delta SD\}$

$\Delta X_{dn(i)}$ = difference of $X \in \{\Delta M_{dn}, \Delta Sd_{dn}\}$ expressed in dn on channel i

RMSE = root mean square error of the calibration model channel i

$lev_{x(i)}$ = leverage of stand x mean intensity on channel i (Weisberg 1995).

3. RESULTS

The coefficients of determination in calibration models are presented in table 3.

Table 3. The coefficients of determination of the models applied in calibration

TM channel	Coefficient of determination at different calibration intervals H93-90	H92-90	H93-92
1	0.66	0.79	0.84
2	0.66	0.79	0.80
3	0.59	0.82	0.75
4	0.93	0.94	0.93
5	0.92	0.93	0.94
6	0.83	0.90	0.73
7	0.80	0.85	0.88

The RMSE's of the regression calibration varied from 0.22 on channel 7 to 0.88 on channel 6 expressed in eight bit digital number (DN) scale.

After regression calibration and studentization, the timing of the changes within the three-year interval did not affect to the separability of the change classes (Figures 1, 2, 3 and 4). The only exception was the regeneration cut where the earlier treatments seemed to have larger spectral responses compared to later ones. However, this was probably due to the small number of observations.. The class 'untreated' did not differ from zero according the T-test at 1% risk. The decreasing response in 'clear cut' is due to soil preparation which was combined with two earlier intervals, but had not yet been accomplished in the later interval (Figures 1 and 2)

The separability of different forest management treatments based on their spectral response was compared between uncalibrated and regression calibrated/studentized difference images with three-year interval between images. According to T-test all the treatment classes were separable at least on one channel based, on differences of stand mean intensities only. The best channels for separating different treatments were TM 2,3,5 and 7. None of the change classes were separable on channel four. The calibration error was relatively small compared to spectral changes due to treatments (Figures 1,2,3 and 4). However, the channels from which the different treatments were separable varies between uncalibrated and regression calibrated/studentized calibration alternatives.

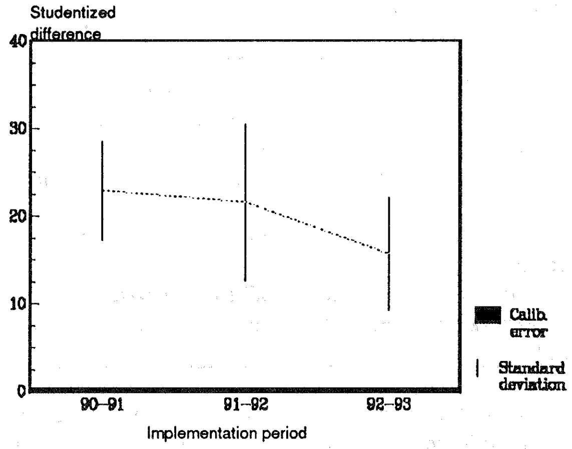

Figure 1. Spectral change of clear cut on the difference image H93-90, TM channel 3.

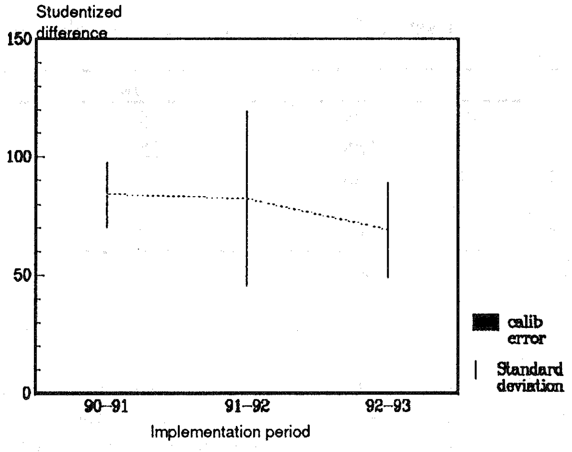

Figure 2. Spectral change of clear cut on the difference image H93-90, TM channel 5.

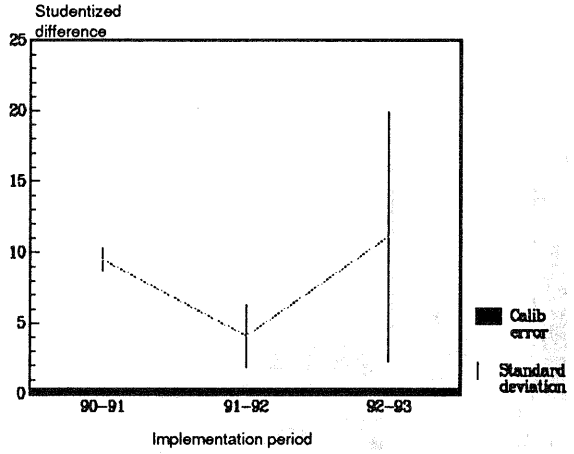

Figure 3. Spectral change of preparatory cut on the difference image H93-90, TM channel 3.

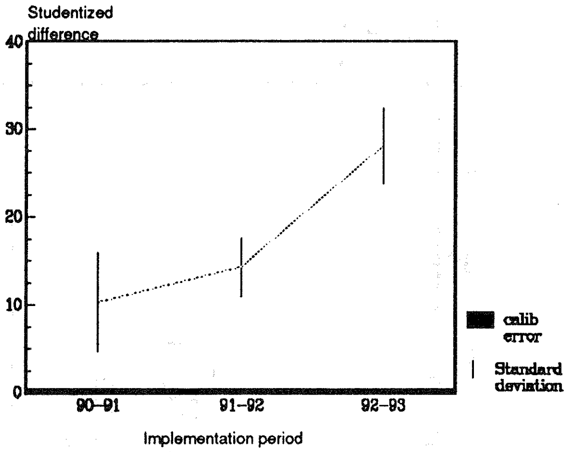

Figure 4. Spectral change of preparatory cut on the difference image H93-90, TM channel 5.

The possibilities for applying generic training data for supervised change detection was studied by comparing the spectral change of different treatment classes between different regression calibrated/studentized image pairs. All the spectral changes between the three image pairs form the same geographic location were at comparable level except on channel four (Figures 5, 6, 7 and 8). However, the image pair from different geographic locations showed generally lower spectral change on all the treatment classes. The treatment class 'uncommercial thinning' was not clearly separable on any channel. Channel four showed varying DN change between the image pairs (Figure 7.). The same effect was noticed on channel 7 with treatment class 'uncommercial thinning' (Figure 8).

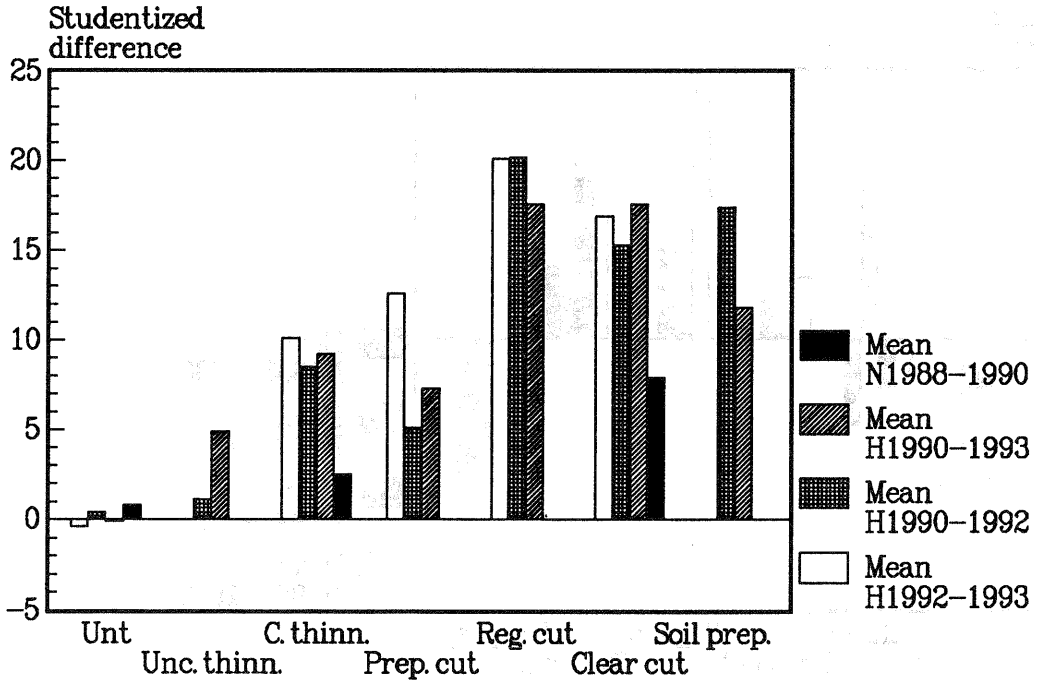

Figure 5. Studentized differences of treatment class means on different image pairs on TM cannel 3.

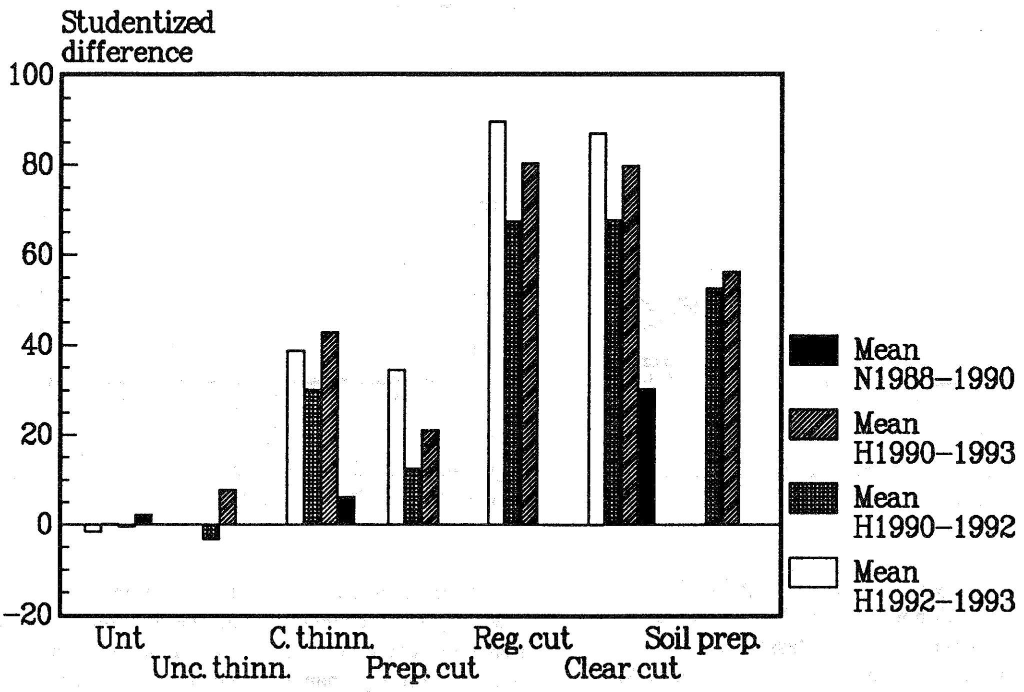

Figure 6. Studentized differences of treatment class means on different image pairs on Landsat TM channel 5.

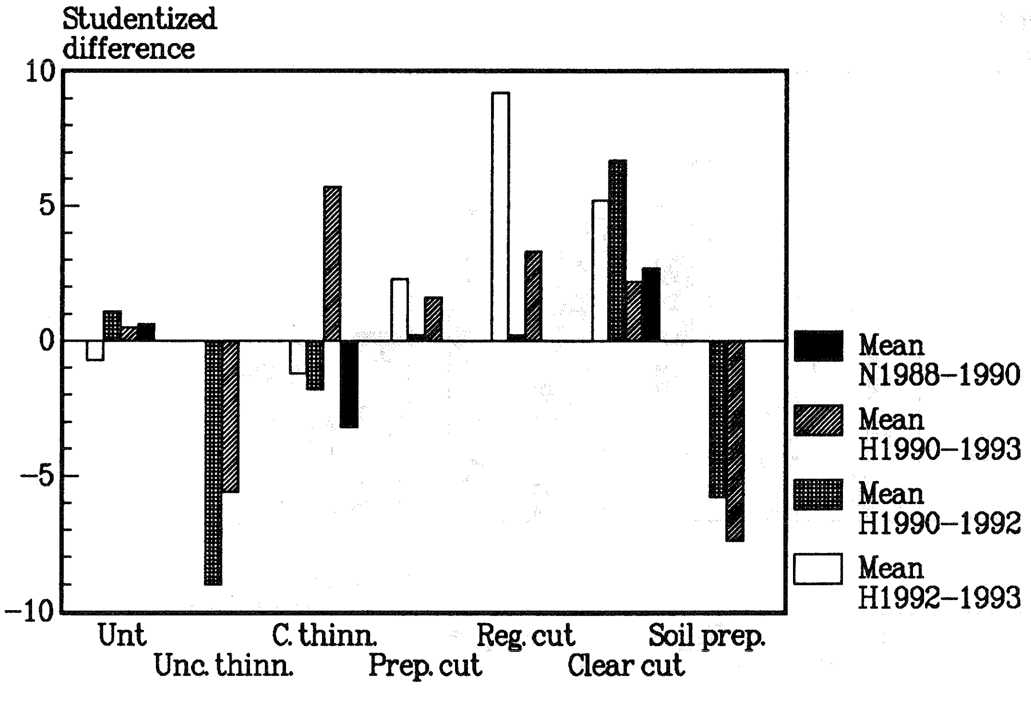

Figure 7. Studentized difference of treatments class means on different image pairs on TM channel 4.

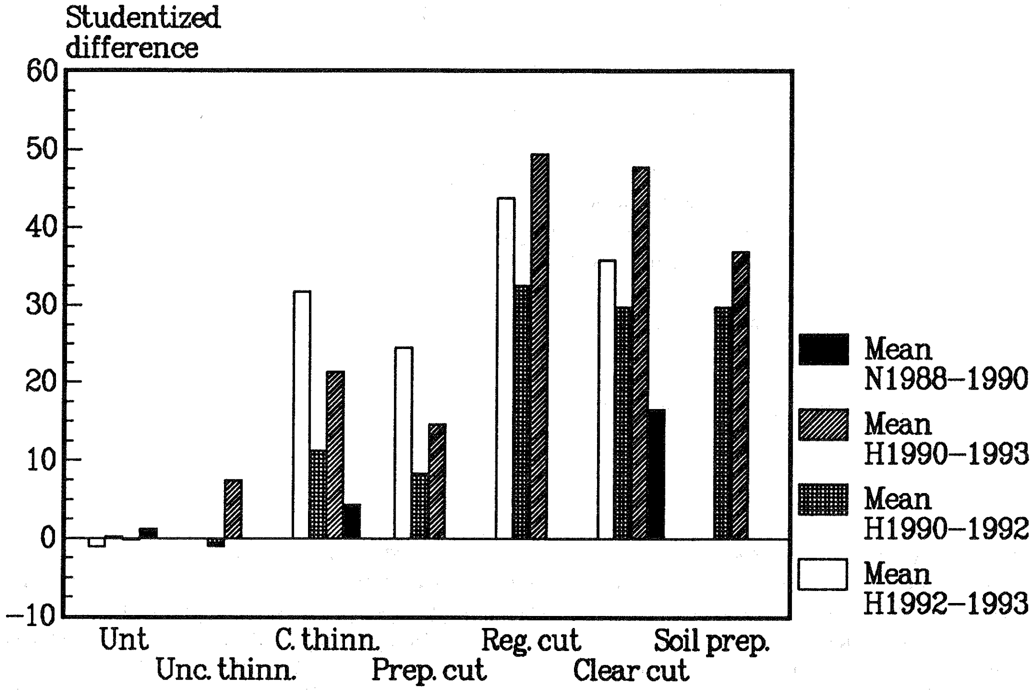

Figure 8. Studentized difference of treatment class means on different image pairs on TM channel 7.

4. CONCLUSIONS

Two problems in relation to preparing generic training data for forest change detection were studied. First the effect of timing of changes to spectral response of changes within three year interval between Landsat TM images was focused on. It was demonstrated that the timing of the changes within this period did not affect the spectral separability of the treatment classes under question. Secondly, possibilities to compose generic training data for supervised change classification was studied. It was demonstrated that after regression calibration and studentization, the image pairs covering the same geographic location could be put to the same level. Range scaling seems still necessary for making image pairs from different areas radiometrically comparable after the calibrations proposed. However, the data available was too limited to make any final conclusions. It was estimated that based on the calibration methods proposed, the silvicultural treatments can be separated at stand level. In addition, it can be expected that the forest damages at the magnitude level of thinnings, for example, can be separated. This means that the 20-30 % defoliation or wind damage should be separable. However, the spectral changes caused by normal growth after the canopy closure will not be separable on stand level in short intervals in the Boreal Forest conditions

REFERENCES:

Häme, T. 1991. Spectral interpretation of changes in forest using satellite scanner images. Acta Forestalia Fennica, 222, pp. 1-111.

Olsson, H. 1993. Regression functions for multitemporal calibration of Thematic Mapper data over boreal forests. Remote Sensing of Environment, 46, pp. 89-102.

Olsson, H. 1994. Monitoring of local reflectance changes in Boreal Forests using satellite data. Report 7, Swedish University of Agricultural Sciences, Remote Sensing Laboratory, Umeå, Sweden.

Rousseeuw, P.J. and Leroy, A. M. 1987. Robust regression & outlier detection. John Wiley & Sons. New York, Chichester, Brisbane, Toronto, Singapore, pp. 1-329.

Singh, A. 1989. Review article - digital change detection techniques using remotely-sensed data. International Journal of Remote Sensing, 10(6), pp. 989-1003.

Varjo, J. 1996. Controlling continuously updated forest data by satellite remote sensing. International Journal of Remote Sensing, 17(1), pp. 43-67.

Varjo, J., and Folving, S. 1996. Regional monitoring of forest changes using unsupervised methods; a case study from Boreal Forest on mineral soils. Submitted to Scandinavian Journal of Forest Science.

Weisberg, S. 1985. Applied linear regression. John Wiley & Sons, New York, Chichester, Brisbane, Toronto, pp. 97-119.