MULTISPECTRAL REMOTE SENSING TECHNIQUES APPLIED TO THE STUDY OF ECOTONES

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ABSTRACT

This paper presents a method of detecting and extracting ecotones on multispectral airborne scanner-images. Ecotones are transition zones between ecotopes, they are regions of high heterogeneity and diversity of landscape-ecological factors (e.g. relief, vegetation, species). A method for extraction of transition zones has been developed on the images of an overflight over agricultural and forest areas near the city of Nürnberg, Germany, in 1995, with the airborne scanner Daedalus AADS 1268. This instrument was operated for a relatively high spatial resolution (70cm at 300m flight hight). It has 11 spectral channels.
As a first step the illumination-independent reflectances of ground pixels were determined by standard procedures. Subsequently the variance of the reflectances in a sliding window were calculated for every spectral channel and summed over all channels. The resulting value was assigned to the pixel in the center of the sliding window, providing a new map. This reflectance 'variance map' represents the heterogeneity in the spectral reflection in the analyzed image.
The variance maps of two transition zones, forest to meadow and agricultural field to agricultural field, have been computed. A correlation between the extracted regions of high heterogeneity and the ecological transition zones (ecotones) could be shown.

1 INTRODUCTION

The basic unit in a landscape is the ecotope (Naveh and Liebermann, 1994). It is the smallest landscape unit, which is at least homogeneous in one landscape feature (Geoecofactor) (Leser, 1991). For this reason most studies examine ecotopes. Since a few years another landscape element, the ecotone, gets more and more into focus of research projects. An ecotone can be described briefly as the boundary between ecotopes. This border is not a sharp edge in mathematical sense, without any spatial extension. It is a region where one ecotope passes over to another one. That means, an ecotone is a transition zone between ecotopes.
Ecotopes are not closed systems, they interact with their environment. An ecotone is therefore an interaction zone.
The ecotone is responsible for the transport (flow) of energy, materials and organisms from ecotope to ecotope (Hansen and di Castri, 1992). Likewise a lot of transport takes place along ecotones, which is significant for the functionality of individual ecotopes.
Based on the importance of ecotones in landscape ecology, we present a method of detecting and extracting the ecotones on multispectral airborne scanner-images, for the purpose of analyzing structural features of ecotones with remote sensing techniques.

2.0 MEASUREMENTS

Multispectral images from an overflight over agricultural and forest areas near the city of Nürnberg, Germany, in 1995, with the scanner Daedalus AADS 1268, has been used for this study. The overflight took place in cooperation with the DLR, Oberpfaffenhofen (Deutsches Forschungszentrum für Luft- und Raumfahrt) and was accompanied by ground reflection measurements with the spectroradiometer IRIS Mark IV (Kollewe, 1995). The scanner Daedalus has a relative high spatial resolution of 2.5 mrad (70 cm at flight height 300 m) and 11 spectral channels. It has eight channels in the visible and near infrared range (0.42 - 1.05 µm), two channels in the midrange infrared (1.55 - 2.35 µm) and one channel in the thermal infrared (8.5 - 13 µm).
From the Daedalus images illumination-independent reflectances have been determined, which yield reflectance-images. The high spectral resolution of IRIS Mark IV (spectral range: 300 - 3000 nm in 862 channels) has been used to improve the accuracy of the Daedalus calibration (Kollewe, 1995).

3 ANALYSIS AND RESULTS

Our method is based on the assumption, that the high ecological heterogeneity and diversity in ecotones are linked with areas of high heterogeneity in the measured reflectances of the observed regions. The heterogeneity in the multispectral reflectance images can be described by the local variances of the reflectances. For this purpose the variance of the reflectances in a sliding window, of a given size, were calculated for every spectral channel of the multispectral image. Subsequently the variances of all channels were summed up. The resulting value was assigned to the pixel in the center of the sliding window, providing a new map. This reflectance 'variance map' represents the heterogeneity in the spectral reflection in the analyzed image. Further details of the computation methods can be found in (Neumann, 1996).
The 'variance maps' of two transition zones, forest to meadow and agricultural field to agricultural field, have been computed. A correlation between the extracted regions of high heterogeneity and the ecological transition zones (ecotones) could be shown.

3.1 TRANSITION FROM FOREST TO MEADOW

One sample was the transition zone forest to meadow. The examined landscape scene is shown in Fig. 1 (Ground resolution 0.75x0.75m², flight height 300m). The left part of area 1 consists of deciduous trees, on the right side is a meadow, which is periodically mowed. The mowing up to the trees prevents growth of smaller trees and bushes. For this reason the transition forest to meadow is smaller (sharper in the airborne images) than it would be in wilderness. The scene contains also unpaved parts, a small lake and a conifer stand (lower right), as well as an area of small garden lots, each which a garden house (upper left).
Because of the high internal heterogeneity of forests, especially on submeter resolution images, we used two sets of source images for the 'variance method'. At first the described reflectance image and additionally a smoothed version of the same image. The smoothing was done with a median-filter with window size 15x15 Pixel (11x11m²). The result is an artificially deteriorated spatial resolution of the original image (Fig. 2).
For the further analysis the variance method was used with different sizes of the sliding window. The best results were reached with window sizes of 3x3 (2x2m²) and 5x5 (3.5x3.5m²) pixel. The calculated

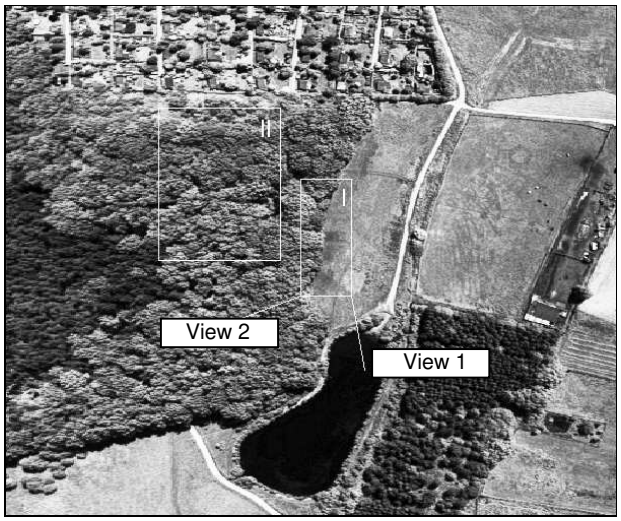

Figure 1: Image Forest-Meadow (1995, Channel 6)
(Analysis of different views see later text)

Fig. 2: Image Forest-Meadow After Smoothing
(1995, Channel6, Median-Filter 15x15)

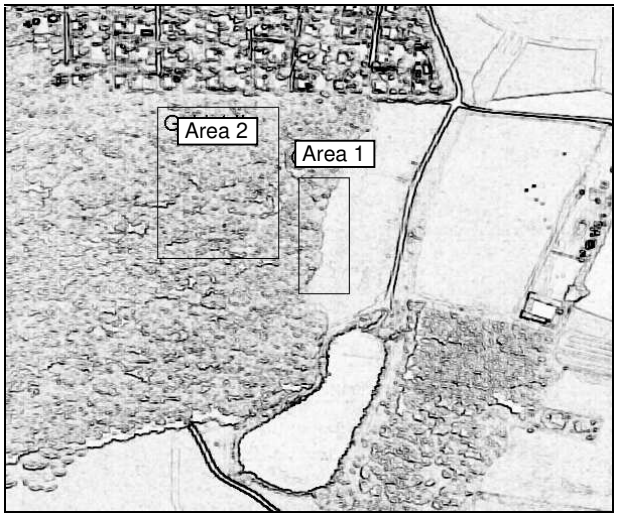

Fig. 3: Variance Map Forest-Meadow
Window Size 3x3

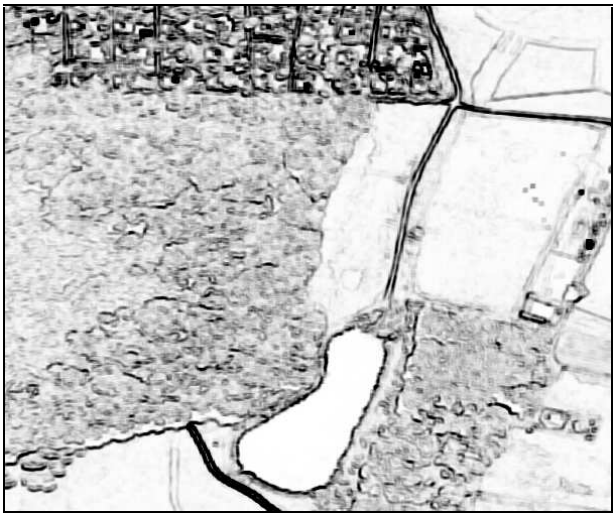

Fig.4: Variance Map Forest-Meadow
Window Size 5x5

variance maps of the original image are shown in Fig. 3 und Fig. 4 and for the smoothed image in Fig. 5 and Fig.6. The gray value represents the variance (white - low variance; black - high variance).
A lot of transitions are extracted on the Variance Maps of the original image (Fig. 3 and Fig. 4; without smoothing). For example the lake and paths are clearly framed by zones of high variance. It is conspicuous, that the forest has a relatively high internal variance and a weaker delineation to the environment than lake and paths. Especially the forest edge above the lake appears very weak in the variance map. Most obviously the fragmentation of the high variance zones in the region of forests is reduced with increasing window size.
On the variance maps of the smoothed image (Fig. 5 and 6) only few prominent transition zones are emphasized. The forest areas are getting more homogenous. A transition zone between conifers (darker forest region on the very left) and deciduous trees (brighter right forest region) could be detected (arrows

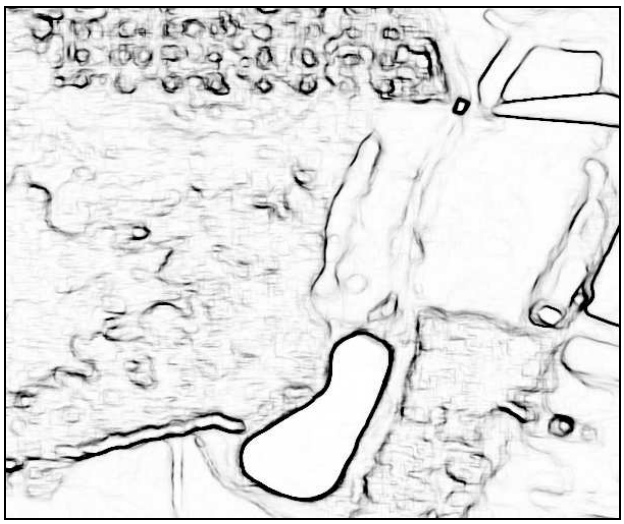

Fig. 5: Variance Map Forest-Meadow (Smoothed) Window Size 3x3

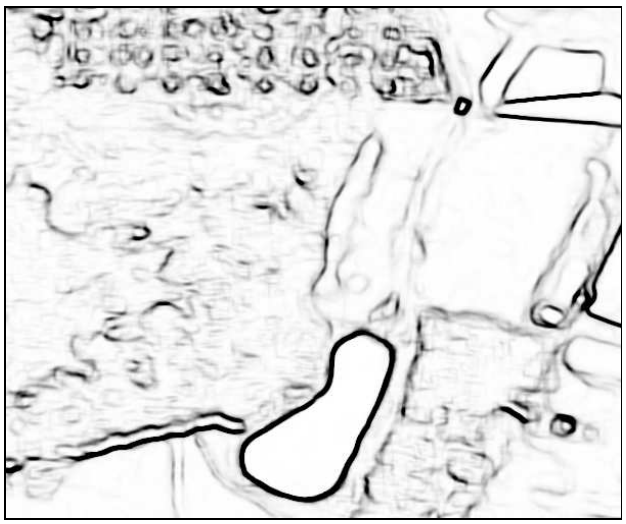

Fig. 6: Variance Map Forest-Meadow (Smoothed) Window Size 5x5

in Figs. 5 and 6). The paths signature nearly disappeared and the lake is framed stronger as before. The regular pattern of garden houses sticks out clearly (upper left). They represent strong transitions to the surrounding vegetation. The forest edge on the lower left has a double structure, because it is accompanied by a strip of shade (see Fig. 1). Generally smaller structures tend to disappear and the main structures getting clearer.

The forest boundary above the lake is of special interest. In the variances maps of the smoothed image the boundary is a clearly marked transition zone. On the other hand the forest boundary on the variance maps of the original image (Figs. 3 and 4) has no sharp border. Hence, for the study of forests and detecting their transitions to the environment the application of a median-filter is useful.

The representation of the variance maps as two dimensional gray scale images provide a good overview. In order to examine smaller transition areas a representation in three dimensional contour plots turned out to be more useful. In such representation the variance map is equivalent to a two dimensional surface (axes [x, y]) in a three dimensional space. The 'height' of the surface (z-axis) is the variance of the variance map at the position (x,y).

The variance map of area 1 is shown as a contour plot in Fig. 7 (window size 3x3) and Fig. 8 (window size 5x5) without smoothing (perspective corresponding direction of view 1)

In both diagrams the meadow is clearly recognizable as a relatively flat area in front of the high values for the forest. It has low variance values, i.e. small variation. The forest in the left part of the diagrams has high variations of the variances. The border between the both regions does not form *one* pronounced maximum, expected ideally for a transition between two homogenous areas. Instead the border is fragmented. By comparison of Figs. 7 and 8 it can be recognized, that the maximum gets clearer by the use of larger windows for variance calculation

In order to reduce the high fluctuation in the forest region, the source data had to be smoothed, again with a median-filter. The changes of the variance maps of the area 1 are shown in Figs. 9 and 10 (for the 3x3 window, seen from the different perspectives shown in Fig.3).

As the diagrams show, the values for the region of meadow hardly changed. Except for a local maximum in the front of the main transition edge, there are only small fluctuations of the variance values in the meadow. The change is significant in the forest region (left part of Fig. 10). The enormous fluctuations

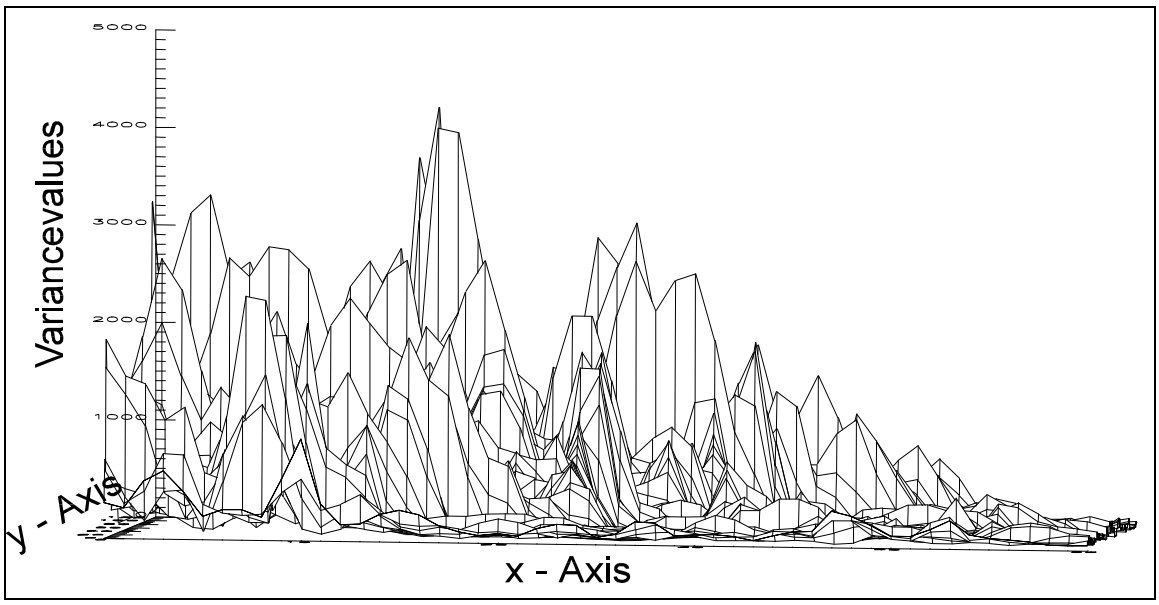

Fig. 7: Contour plot of variance map area 1 (variance window size 3x3, no smoothing, view 1)

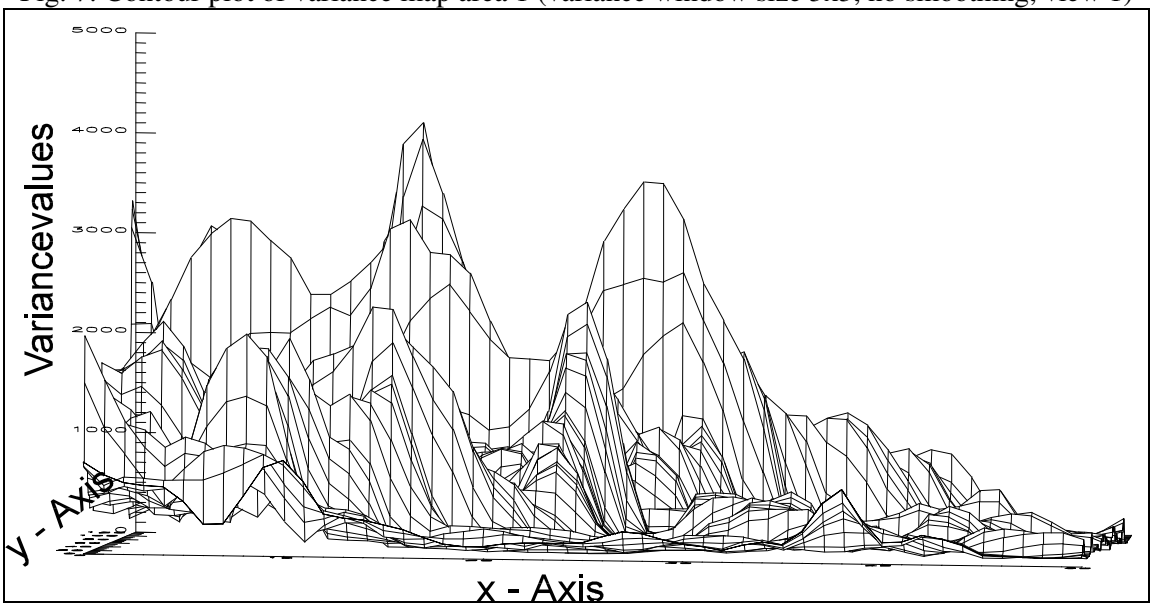

Fig. 8: As Fig. 7, but for variance window size 5x5

have been reduced due to smoothing. The variance values are still (four times) higher as in the meadow area. By the smoothing of the image the transition zone from forest to meadow is displayed as a distinct maximum in the contour plots. This maximum has only a small width, which results from the sharp break between forest and meadow described earlier.

3.2 TRANSITION FORM AGRICULTURAL FIELD TO AGRICULTURAL FIELD

The second sample examined was an area of agricultural fields. The scene studied is shown in Fig. 11. Two transition zones between agricultural fields are marked in the figure by rectangles A and B.

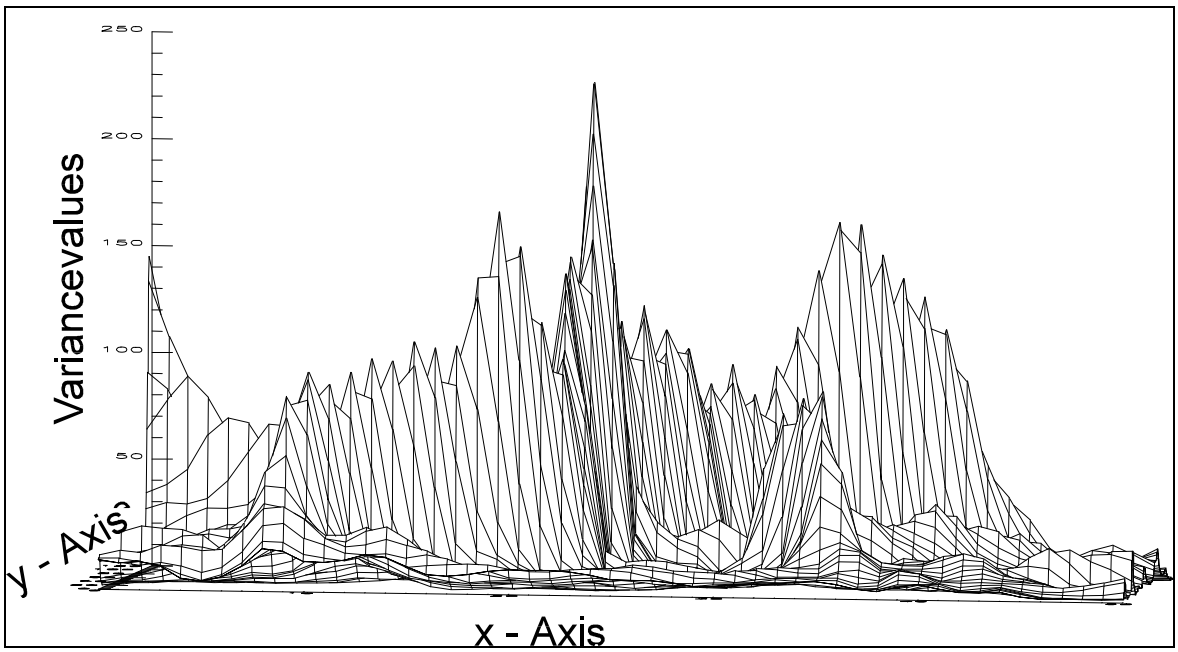

Fig. 9: As Fig. 7, but with smoothing

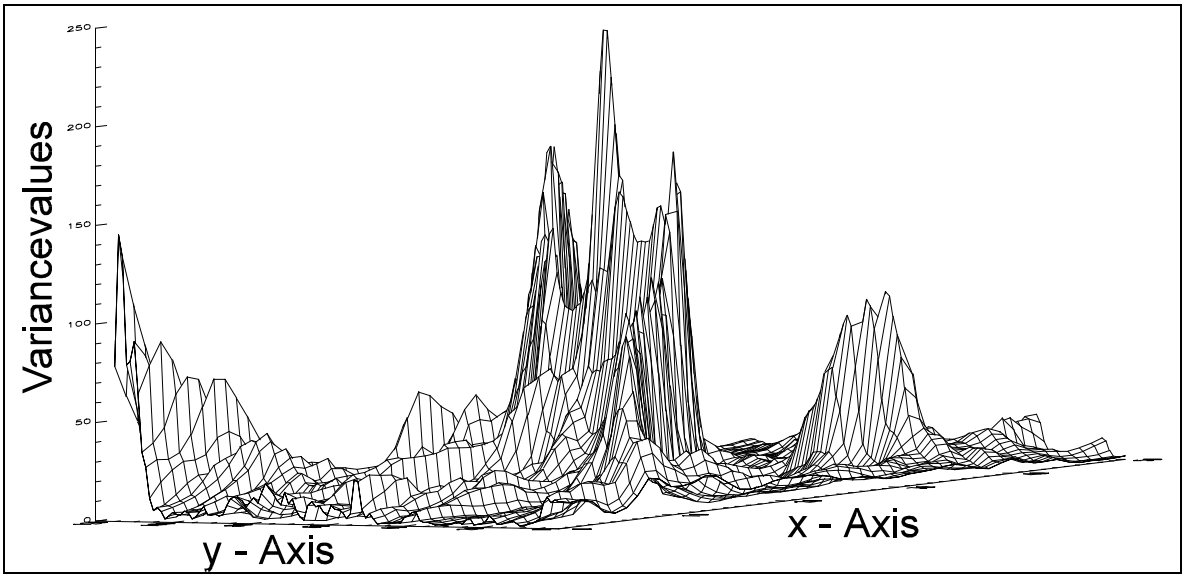

Fig. 10: As Fig. 7, but view 2 and with smoothing

They are used for the further analysis. Fig. 12 represents the calculated variance map of the sample. The applied window size was 5x5 pixels

3.2.1 Area A

The transition in area A has a high contrast, that means the average spectra of both fields differ very much. In Fig. 12 the transition zone can be seen as a black line. If area A is displayed in a contour plot (as described above), it forms a distinct maximum. The background is nearly flat due to the highly homogenous structure of the examined fields. The transition zone between fields is a sharp border, and

Fig. 11: Image 'field to field' (1995)

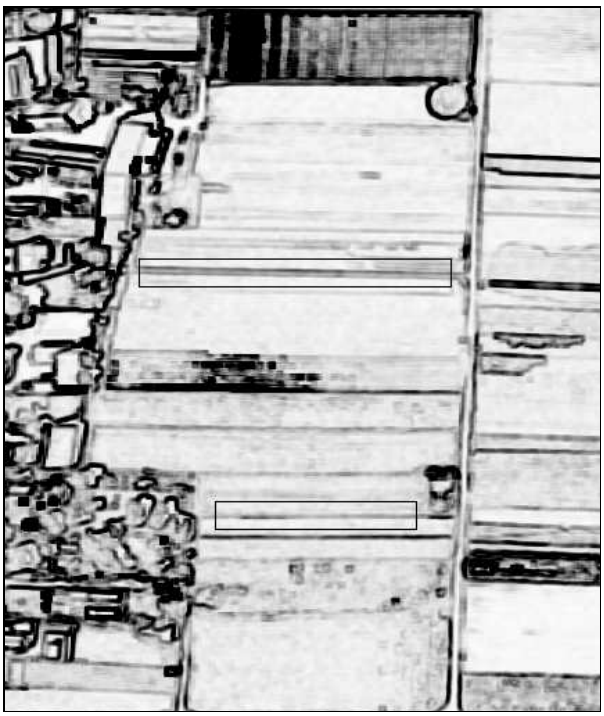

Fig. 12: Variance map of Fig. 11 (Window 3x3)

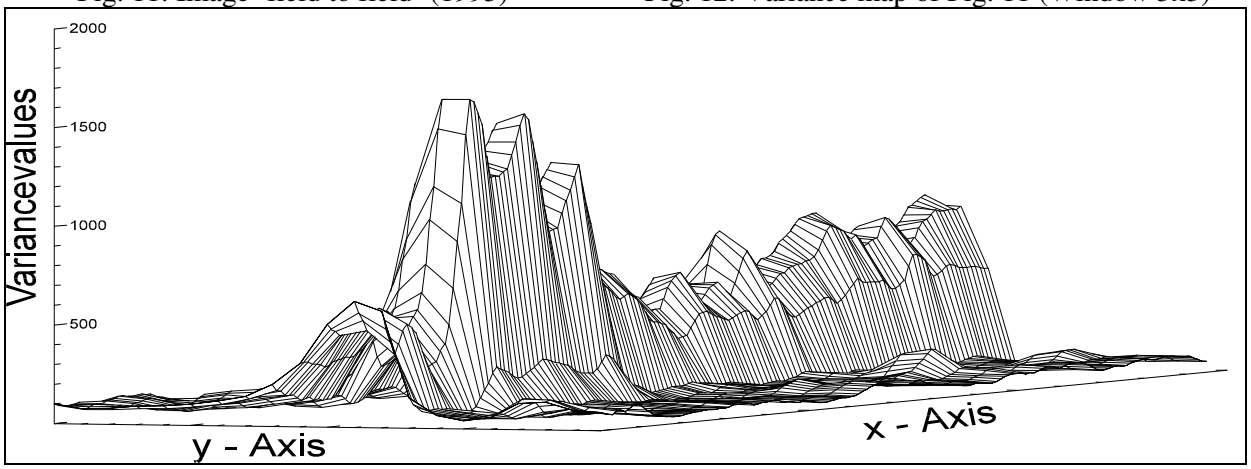

Fig. 13: Contour plot of variance map of Area A (in Fig. 11)

the variance method results in a thin, sharp variance maximum. Such transition zones could be detected and extracted automatically.

3.2.2 Area B

In area B two fields are separated by a small sandy path. This sample demonstrates the problem of the spatial resolution. A threshold for the width must be defined to distinct a simple edge from a transition zone.

The upper contour plot in Fig. 14 shows a clear maximum. It looks similar to the one of area A. The background is nearly flat and the maximum has steep flanks. In Fig. 14, bottom, the same contour is shown seen from another aspect. It can be recognized, that the sandy path between the fields causes a

local minimum between two maxima. If the window size for the variance calculation would be smaller (e.g 3x3), this minimum would be more significant. Although the sandy path is smaller than the variance window (3 pixel width = 2 m), it could be resolved by the variance method.

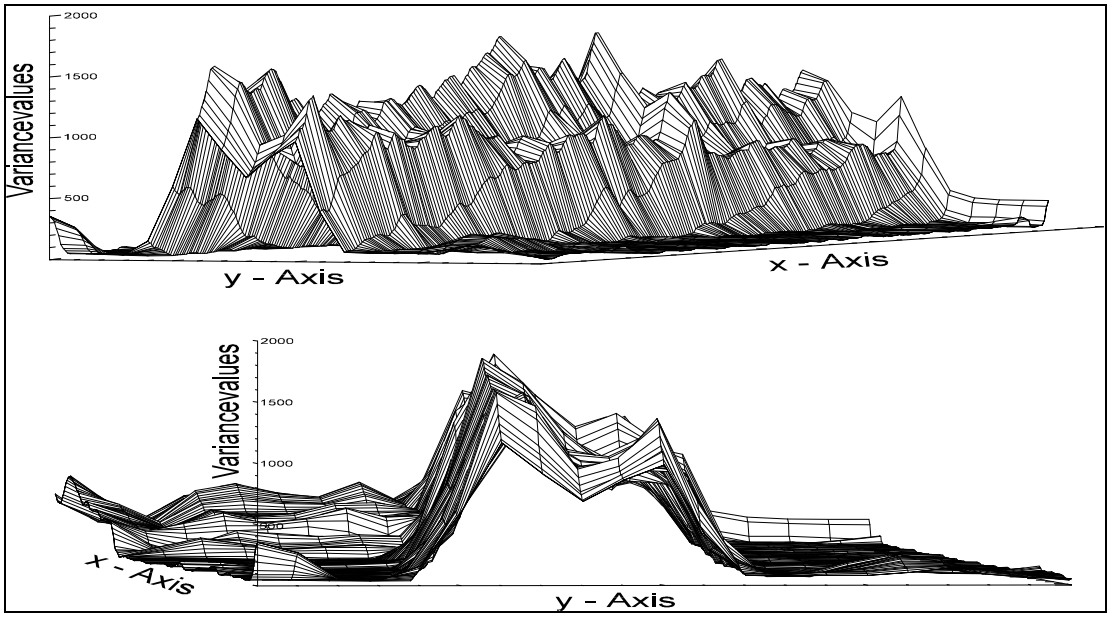

Fig. 14: Contour plot of variance map of Area B (in Fig. 11)

4 SUMMARY

The purpose of this study was to develop a method for analyzing structural features of ecotones with remote sensing techniques. The developed variance method calculates a map of the fluctuation in the spectral reflectance. This map extracts regions of high heterogeneity. The method was applied on samples of transition zones from forest to meadow and from field to field. These transaction zones have been successfully extracted, and are highly corresponding with the landscape ecological ecotones.

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