ANALYSING AN ATM-SCANNER FLIGHT OVER THE CITY OF DRESDEN TO IDENTIFY URBAN SEALING

Gotthard Meinel, Maik Netzband, Volker Amann*, Rolf Stätter*, Georg Kritikos*
Institute of Ecological Spatial Development, Dresden, Germany
*Department of Optoelectronics, German Aerospace Research Establishment, Oberpfaffenhofen, Germany

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ABSTRACT:

Increasing soil sealing in urban agglomerations results in negative consequences for urban ecology, especially for urban climate, urban hydrology, and urban biotopes. Decreasing ground-water levels and increasing sewage fees force to control any further soil pavement or, if possible, unseal presently unused areas. According to this development there is a need to produce survey maps in meso-scales and large-scales at reasonable prices and in fair quality. The entire terrestrial taking of soil sealing degrees in urban agglomerations is as highly cost-intensive as it is time-intensive. This is not likely to be financed so the use of remotely sensed data seems to be much more suitable to produce such maps for urban planning.
Based on a DAEDALUS-ATM-Scanner flight mission the Institute of Ecological Spatial Development works out the analysis by developing three different methods to determine soil sealing in urban areas. The first method is to calculate a sealing degree (artificial soil cover in percent) using the vegetation index NDVI. This index is very sensitive to separate areas covered with vegetation (mostly unsealed) from areas without vegetation and therefore mostly paved. A threshold operator is used on visual determination which makes it possible to calculate a sealing picture.
Secondly, the data from the thermal infrared band obtained by a late-evening flight (after dusk) and an early-morning flight (before dawn) are used to identify traffic areas because they are strongly overheated.
Finally, a hierarchical land-use classification of a 15-band multispectral data set will be carried out. The data set contains DAEDALUS bands 1 to 10 (visible, near and middle infrared), thermal infrared information about the three flights (noon, late-evening and early-morning), differences of soil temperatures between late-evening and early-morning, and the vegetation index NDVI. In combination with the other two methods soil sealing maps are going to be produced.

ZUSAMMENFASSUNG:

Die negativen Folgen übermäßiger Versiegelung von Stadtzentren auf Stadtklima, Wasserhaushalt, Boden, Flora, Fauna und Stadthygiene sind hinlänglich bekannt. Insbesondere steigende Abwassergebühren und sinkende städtische Grundwasserstände zwingen zur Kontrolle und teilweise zu Entsiegelungsmaßnahmen. Hierzu sind mittel- und großmaßstäbige Versiegelungskarten Voraussetzung. Diese müssen kostengünstig und in genügender Qualität erarbeitet werden. Da die terrestrische Aufnahme von Versiegelungskarten sehr teuer und damit meist nicht finanzierbar ist, bieten sich fernerkundliche Methoden zur Kartenerstellung an.
Drei Auswerteansätze zur Bestimmung städtischer Versiegelung auf Basis einer multitemporalen Daedalus-ATM-Scannerbefliegung werden vom Institut für ökologische Raumentwicklung e.V. Dresden entwickelt und hier erläutert. Erstes Verfahren ist die Bestimmung des Versiegelungsgrades über den Vegetationsindex NDVI, der sehr sensibel vegetationsbestandene (und damit in der Regel unversiegelte) von vegetationsloser (und damit gewöhnlich versiegelter Fläche) trennt. Über einen angeschlossenen Schwellwertoperator kann nach visueller Ermittlung eines Trennwertes ein Versiegelungsbild berechnet werden. Zweitens kann über die Thermaldaten einer Abend- und Morgenbefliegung auf Verkehrsflächen (versiegelte Freiflächen) aufgrund ihrer starken Überwärmung geschlossen werden. Drittens wird eine hierarchische Klassifikation auf Basis eines 15kanaligen Bildes, welches neben den 10 optischen ATM-Kanälen, die Thermalinformationen von Mittag-, Abend- und Morgenflug sowie das NDVI-Bild enthält, durchgeführt und daraus eine Versiegelungskarte abgeleitet.

1. INTRODUCTION

Sealing of urban surfaces is connected with negative ecological consequences. Effects on hydrology (water budget), micro-scale and meso-scale climate are well known and precisely described in literature (SUKOPP & WITTIG, 1993). The supply of drinking-water has become a problem. Ground water levels have decreased in urban agglomerations, costs for sewage fees have immensely augmented, and an excessive surface run-off causes unexpected floods. Thus cities are forced to establish more drain areas to reduce new sealing of soil or even unseal unused areas.

To judge planned building projects and, if necessary, to prevent such projects, and besides to use existing instruments to decover areas planners need to have survey data and maps with information about scales of sealing in urban areas. To get an overview over town quarters a map scale of 1 : 25 000 is sufficient, whereas for more detailed planning a scale of 1 : 5 000 is needed. These maps can be produced by innovative and efficient methods using remotely sensed data.

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2. DATA ACQUISITION

2.1 Flight Mission

The following investigations are based on a flight mission over parts of the City of Dresden, Germany.

The chosen flight areas cover 40 test sites (145,3 ha) where a terrestrial investigation of soil sealing was undertaken by collaborators of the Institute of Ecological Spatial Development (Heber, 1993) over the last years. Most of typical surface cover materials in urban agglomerations are also recorded in the flight area.

	Flight Area West (1)	Flight Area Centre (2)	Flight Area East (3)
Length in m	4 200	9 000	5 800
Scan rows	4 000	8 000	5 100
Width in m	2 200	2 700	2 700
Number of flight stripes	3	4	4
Total area in km^2	13,3	23,5	18,0
Flight path direction	WNW-ESE	SSW-NNE	NW-SE
Number of covered test sites	9	17	14
Total area of test sites in ha	28,3	84,3	32,8

Table 1: Geometric Parameters of the Three Flight Areas

The flight mission was performed by the "Department of Optoelectronics" of the "German Aerospace Research Establishment (DLR)". The aircraft was equipped with a DAEDALUS-ATM-Scanner AADS 1268. With a flight altitude of 500 meters the resolution was 2,5 mrad IFOV (Instantaneous Field of View) and flight paths had a lateral overlap of 40 %.

In total four flights were carried out, one flight at high noon, two flights after dusk and one flight before dawn. Table 2 shows it in detail:

Date	Time	Comments
10.08.95	12.40 - 13.43	Multispectral data (12 bands) and, additionally, taking of CIR aerial photos
10.08.95	21.08 - 22.14	Only thermal infrared data (band 11), not processed yet as the morning flight was broken off (technical problems)
11.08.95	20.59 - 22.07	Thermal infrared after dusk
12.08.95	04.16 - 05.22	Thermal infrared before dawn

Table 2: Program of the Scanner Flight Mission 10.-12.08.1995 for Dresden, Germany

During the evening and morning flights only data from thermal infrared bands were recorded, as there were all bands registered during day time.

Band 12 is spectrally similar to band 11, but because band 11 was partly overmodulated, the intensification of band 12 was reduced. Simultaneously to scanner recording, CIR photos were taken by a specific camera called Zeiss Reihenmeßkammer (RMK) A15/23 (calibrated focal constant = 153 mm), which was equipped with a KODAK Aerochrome Infrared 2443 film. A Zeiss filtertype D (Diaphragm 5,6; exposure 1/200) was used. The photo scale was 1 : 3 000, the forward overlap was 60 %, and the side overlap was 40 %.

The weather conditions during flight time were extremly fine, no clouds and little humidity. Parallel to the airborne measurements the meteorological parameters temperature, steam pressure, wind direction, and wind speed were recorded on two fixed locations. Along three parcours in the overflown area temperature and steam pressure were also recorded.

2.2 Quality of Scanner Data

Because of good recording conditions and long-time experience of the "DLR"- colleagues the quality of received data is excellent. The geometric resolution of digital scanner data is 1,1 m. Only eight lines were not recorded.

During the noon flight the air temperature was very high (about 26 °C), so that surface temperatures in thermal infrared band 11 sometimes increased over the blackbody temperature of 48,5 °C. This increase could partly be avoided in band 12 by reducing the intensification. In this band there are also some overmodulations contained with the typical shade effect of 2 pixels. The remission of metal and glass roofs gives wrong temperature information, because the degree of emission ε is less than 0,98 (ε_{metal}: 0,01 - 0,05; ε_{glass}: 0,94) which is assumed as standard.

The flight parameters were stable because of good wind conditions, so there was little roll, crob, and pitch distortion. This condition was very helpful to find the ground control points to rectify data.

The days of flight mission followed a long, dry period with high temperatures, so especially short-cut grass was thoroughly dried out.

Although the flight altitude was only 500 m above ground-level and the air was very dry an atmospheric correction of an evening flight stripe and a morning flight stripe was tested. To calculate the correction it is necessary to integrate the temperature and humidity values of a radiosonde (weather balloon) during flight time and to combine them with the pressure and trace gases of a standard summer atmospheric condition. The comparison of the original data set with the atmospherically corrected picture shows mostly constant temperature differences of 1 - 1,5 °C higher temperature in the corrected pictures. This moderate difference can be explained with the little difference between soil temperature and air temperature of evening and morning flights. For that reason a costly atmospheric correction is not necessary for the complete data set.

2.3 Reference Data

For the presented steps the following data were used:

- topographic maps (scale 1 : 10 000)
- boundaries and sealing degrees of 40 terrestrial test sites (total area of 145,3 ha)

For further analyses and as a reference for all test sites the following data shall be integrated:

- map of biotopes (scale 1 : 10 000) including sealing degree values divided in five classes
- layer of buildings taken from topographic maps (scale 1 : 10 000)
- maps of sealing degrees calculated from satellite data (Landsat-TM and SPOT-XS)

3. DATA PREPROCESSING

3.1 Data Calibration

The scanner data have to be converted in true reflection values and temperature values using the recorded flight parameters. Each pixel value has to be calibrated with the following formulas:
for the optical bands 1 - 10 :

$$\textit{Calibrated Radiances } L_i = C * (D_i/G - D_{BB1}) \qquad (1)$$

and for the thermal infrared band 12:

Calibrated Radiation Temperature

$$T_i = T_{BB1} + (T_{BB2} - T_{BB1}) / (D_{BB2} - D_{BB1}) * (D_i - D_{BB1}) \qquad (2)$$

parameters:

D_i	-	Video Count
C	-	Calibration Factor
G	-	Gain
D_{BB1}	-	Blackbody 1 Count
D_{BB2}	-	Blackbody 2 Count
T_{BB1}	-	Temperature of Blackbody 1
T_{BB2}	-	Temperature of Blackbody 2

3.2 Geometric Rectification

Data are rectified using the rectification software PRESDO (JANSA, 1983). Therefore about 30 ground control points per km² were marked as points in the scanner data and in scanned topographic maps at the same time (scale 1 : 10 000), so altogether about 10 000 ground control points were inserted for all flight stripes. Data are resampled with a resolution of 2 m. A possible resolution of 1 m is avoided, because the necessary storage capacity would be increased by factor 4 (for 2 m resolution 550 MB are needed).

The limited precision of rectification is an argument not to resample down to 1 m. The mean rectification error is therefore 2,5 pixels (5 m), its maximum is 5 pixels (10 m). The software PRESDO only allows a relative rectification of flight stripes on a topographic reference in file coordinates, so the rectified data have to be transformed into Gauss-Krüger-Projection (Bessel ellipsoid) by editing the upper left corner co-ordinates of each stripe.

3.3 Mosaic of Stripes

To compose the rectified flight stripes into complete pictures a mosaic process is needed, which is worked out in the software ERDAS-IMAGINE (8.2). In order not to modify the intensity value of each pixel, i.e. real temperature value, the process is performed without contrast matching. Tests of mosaic with included contrast matching over the whole overlap area partly show unsharpness which can be explained with inaccuracy of rectification. For that reason each flight stripe was cut out in a certain way that the overlap area between two stripes still is only 5 - 10 pixels. A linear rectangular feathering is applied on this remaining narrow unsharp overlap area which connects two stripes.

3.4 Calculating Additional Information Layers

For the estimation of urban soil sealing the vegetation index and the cooling characteristics of certain urban areas are very important.

A cooling is calculated using the difference of evening and morning temperature and displayed in a "cooling picture":

$$\Delta T = T_{evening} - T_{morning} \qquad (3)$$

The vegetation index NDVI (Normalized Difference Vegetation Index) for the whole area is calculated on the basis of the following formula:

$$NDVI_{Scanner} = (\text{Band } 7 - \text{Band } 5) / (\text{Band } 7 + \text{Band } 5) \qquad (4)$$

3.5 Composition of a Multispectral and Multitemporal Total Data Set

For further steps it seems promising to composite all available information layers in one total composition for each flight area. Layer comparison and classification procedures are now easier to handle. For software reasons it is necessary to have all layers in the same format. So the additional calculated auxiliary bands, which were in floating point format, are now transformed to 8-bit unsigned integer format. Table 3 shows the picture composition in detail:

Band No.	Contents
1 - 10	Multispectral bands 1 - 10
11	Calibrated thermal infrared data of the midday flight
12	Calibrated thermal infrared data of the evening flight
13	Calibrated thermal infrared data of the morning flight
14	Difference of temperature values between evening flight and morning flight
15	Vegetation index NDVI calculated from bands 5 and 7

Table 3: Chosen Bands of the Multispectral and Multitemporal Data Composition

3.6 Investigation of Band Correlations

Correlations for each band combination are calculated for the three flight areas and for certain sites. Table 4 gives the the general results.

Correlation r^2	Band combination
$r^2 > 0,95$	1 - 2, 2 - 3, 3 - 4, 3 - 5, 4 - 5, 7 - 8
$0,95 > r^2 > 0,90$	1 - 3, 2 - 4, 2 - 5
$0,9 > r^2 > 0,85$	1 - 4, 1 - 5, 3 - 6, 4 - 6, 4 - 10, 5 - 6, 5 - 10, 6 - 9, 9 - 10
$0 > r^2 > -0,5$	3 - 15, 6 - 15, 10 - 15, 11 - 15, 12 - 15, 13 - 15
$-0,5 > r^2$	1 - 15, 2 - 15, 4 - 15, 5 - 15

Table 4: Correlation r^2 of certain Band Combinations out of the 15-band Total Data Set (description of bands see Tab. 3)

The following conclusions can be made:
The band combinations 1 - 2, 4 - 5 and 7 - 8 highly correlate. Information on bands 1, 4, and 8 are mostly included in the bands 2, 5, and 7. It is no coincidence that the spectral areas covered by these bands are not used by Landsat-TM, so these bands can be ignored in multispectral classifications without a serious loss of information.
Very little correlation values can be registered in any combinations with band 15, (vegetation index NDVI). Negative correlation can be explained regarding the calculation formula of NDVI. Only in combination with bands 8 and 7 there is a positive correlation of band 15.

4. ANALYSIS OF DATA FOR SOIL SEALING IN URBAN AREAS

4.1 Registration Problems of Soil Sealing Degrees using Aerial Photos and Scanner Data

Problems occur if items are covered or hidden (trees, underground car parks and planted greenery on roofs):
There is no other way for all remote sensing techniques than looking down to earth's surface. In the case of passive optical sensors there is no chance to look through the upper surface material, so everything underneath is not recorded. As a consequence soil sealing under leaved trees can not be detected. Only with visual interpretation of the surroundings or with additional expert knowledge these areas can be identified.
Furthermore sealed soil of underground car parks, whose surfaces are covered with vegetation, or planted greenery on roofs can not be registered with remote sensing techniques. This is a specific problem of city centres and new residential parks where these kinds of surfaces cover up to 15 % of the total areas.

Precision of soil sealing degree values derived from remote sensing data:
Remote sensing methods can hardly deliver the same exact values as a terrestrial investigation.
This includes the geometric precision as well as the contential precision. Although there are a lot of defined indices to describe soil sealing the "soil sealing degree" is the best index reproduced by remote sensing techniques, because it does not pay much attention to surface material. Other indices, e. g. the "soil function index", which is more sensitive to drain capacity can hardly be reproduced when using remote sensing data. It can only be derived if correlated with the soil sealing degree. Even with the highest geometric resolution small pavement areas or joints are not recordable.

Rectification of Scanner Data:
The rectification of scanner data is a very time consuming and costly task. A large number of ground control points has to be found manually (without automation) and the actual rectification done by a special and expensive software. The costs of data rectification are estimated 2 - 3 times higher than the costs of data acquisition. Possibly by means of very high resolution and precise GPS navigation instruments such high costs could be reduced decisively. This latest technique enables to rectify automatically knowing the precise aircraft position during the whole flight. Such increasing efficiency would make the use of scanner data much more attractive to answer various scientific questions.

Panoramic Distortion by Wide Scan Angle:
The scan angle can reach a maximum of 43° declination from Nadir. This fact causes immense distortions in peripherical zones of scanner stripes, large shaded areas and blind spots, as well as the reproduction of vertical surfaces, e.g. house walls. To reduce this effect the wide side overlap of 40 % is chosen and only the central area of a stripe with its small distortion is then taken at the expense of a more costly acquisition and analysis.

4.2 Vegetation Index as an Instrument to identify Soil Sealing

The vegetation index gives an very precise overview, where earth surfaces are covered with vegetation.

For a multistep analysis strategy the vegetation index NDVI should only be used to separate areas which are covered by vegetation and therefore unsealed (wrong interpretation of underground car parks with plants on surfaces and planted greenery on roofs are inevitable).

Especially in shaded areas a visual interpretation of vegetation cover is hardly possible. Here the vegetation index separates sealed from unsealed areas in detail, although the index is slightly raised in shadow zones.

The vegetation index NDVI can be transformed for each pixel with a linear equation using the extreme values P_{sealed} (100 % sealing, $NDVI_{sealed}$) and $P_{unsealed}$ (0 % sealing, $NDVI_{unsealed}$) in quantitative sealing degree values.

Another analysing method is to identify visually a threshold operator and to use it to transform the vegetation index data set into a binary picture.

The advantage of this simple and practical method faces the following methodological disadvantages:

incorrect sealing degree values for water areas:
Water has a high absorption in red and near infrared spectral range. Thus the calculated vegetation index of water is very low and, after transformation, its sealing values are very high which is wrong. Because of this mistake it is necessary to mask water areas after having carried out a land-use classification or to exclude these areas by digitizing and masking them before classification.

incorrect sealing degree values of unsealed areas without vegetation:
Vegetationless and unsealed surfaces cause a low vegetation index and consequently a high sealing degree value. These areas are therefore wrongly calculated. Number and expansion of such areas are very limited in urban areas. They appear as construction areas, disposal sites, quarries, fields and very intensively used allotments. They can be identified visually and need to be masked.

4.3 Multitemporal Thermal Infrared Data as an Instrument to identify Soil Sealing

Thermal infrared data give information about surface temperatures. They are mostly dependent on surface material, but also influenced by relief, daylight and wind exposition, as well as air humidity. The mean surface temperatures of different materials are determined for each of the three flight dates.

Table 5 shows the temperature values and the calculated cooling values from late evening to early morning.

Surface material	Midday temperature in °C (ca. 13.15)		Evening temperature in °C (ca. 21.30)		Morning temperature in °C (ca. 4.45)		Cooling rate in °C (evening to morning)	
	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
Tarmac road	38,4	3,3	25,0	1,3	16,6	0,8	8,5	0,8
Paved road	33,7	2,1	22,9	1,0	15,5	0,9	6,1	0,9
Concrete road	35,0	1,5	25,1	1,1	16,4	0,8	8,9	0,9
Tile roof	38,0	7,0	18,7	1,9	10,1	1,7	8,7	1,6
Bituminous roof	40,9	5,8	21,9	1,8	12,9	2,2	8,5	1,1
Bare soil	38,1	4,3	18,6	2,5	11,9	2,3	6,8	0,8
Uncultivated field	36,7	2,9	15,7	2,7	11,0	1,6	5,0	1,6
Cultivated field	27,2	3,5	14,9	1,3	10,1	0,8	4,8	1,3
Grass	42,1	2,1	17,2	1,2	10,8	1,0	6,4	0,6
Meadow	32,4	5,4	16,0	1,8	9,5	1,7	6,1	2,0
Tree tops	23,6	2,0	20,9	0,5	12,1	1,2	8,4	1,1
Water	18,6	0,3	21,4	0,2	19,6	0,2	1,9	0,2

Table 5: Temperature Values of Different Surface Cover Materials

Figure 1 shows these temperature distributions in a graphical way:

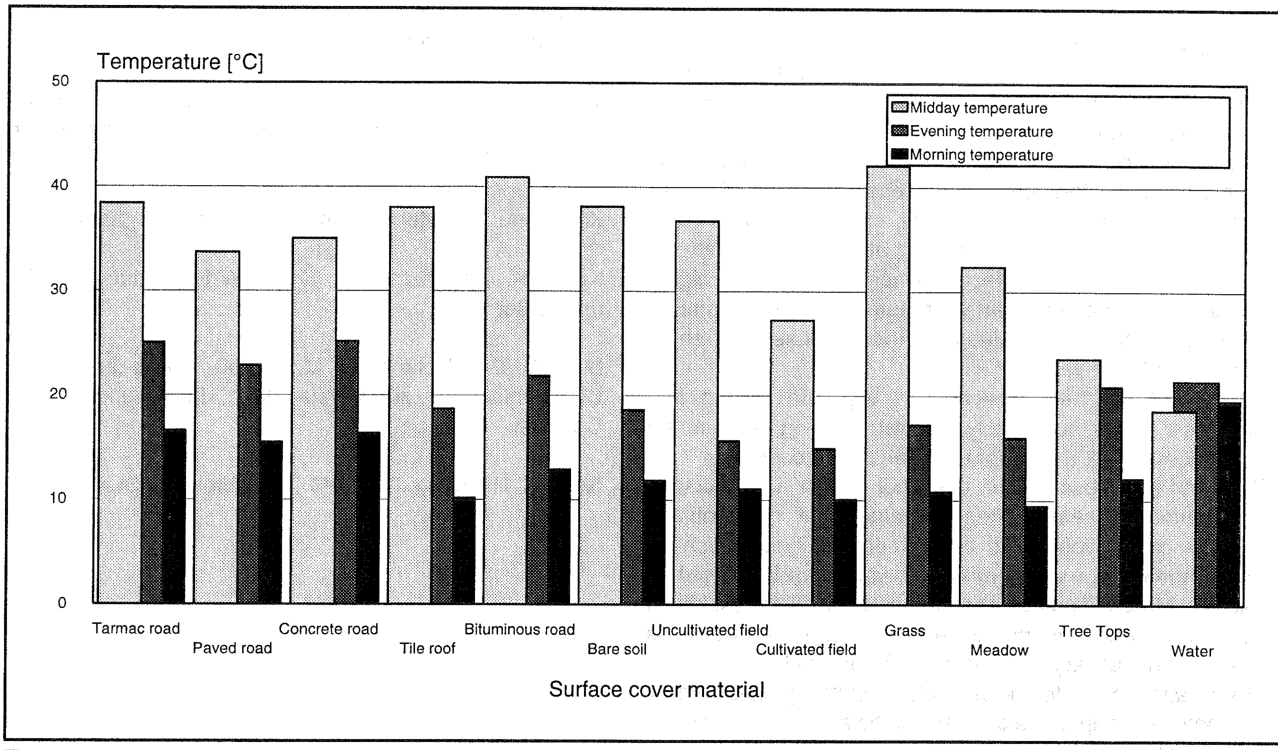

Figure 1: Temperature Values of Different Surface Cover Materials

The following conclusions can be drawn:

- Traffic areas are characterized by high temperatures in the evening and in the morning with little standard deviation. In average the temperatures are 5 °C higher than the temperatures of all other areas. Therefore it is possible to identify these areas by their temperatures.
- Building complexes are typical to possess high heating during day time, and a fast and intensive cooling at night, dependent on their roof material. Even roofs with the same materials vary considerable in temperature, because of different exposition and age of materials.
- Short-cut grass heats up extremely during day time and cools down rapidly after sunset, so the difference between midday and evening temperature is much higher than between evening and morning temperature.
- Meadows heat up moderately and reach the lowest morning temperatures.
- Temperatures of tree tops are not very high at midday and cool down heavily at night.
- Water bodies show a very small variation of temperatures between day and night because of their high thermal store capacity.

An exact and distinct separation of sealed and unsealed areas is not yet reached using the parameter temperature. The cooling characteristics of both types are, not as expected, partly too similar.

Less precise rectification in certain stripes cause misclassifications in merged data. It is expected that the separation between sealed and unsealed areas will not be reached sufficiently because the temperature ranges are too similar and temperatures are influenced by external factors, i. e. relief, exposition, and local climate. Though it is quite likely to determine traffic areas in the evening as well as in the morning data set, because of their significant higher temperature. This characteristical feature is very important to analyse the data with a multi-step method.

4.4 Non-thermal Bands of ATM Scanner as an Instrument to identify Soil Sealing

Apart from the quantitative methods sealing degree values of urban surfaces shall be obtained by performing a detailed land-use classification. Sealed surface classes will be separated for buildings and not built-up sealed areas, as unsealed surfaces will be divided into short cut grass, meadow, trees/shrubs, vegetationless areas and water surfaces. This classification will certainly deliver additional information about further urban ecological research subjects.

First steps to produce this classification have just begun. A hierarchical classification is performed, structured in the following scheme:

- Determination of areas covered with vegetation applying a threshold operator upon the vegetation index NDVI.
- Subdivision of vegetation areas in grass, meadow and trees/shrubs with a Maximum - Likelihood - Classification (ML).
- Separation of traffic areas (not built-up but sealed) using a threshold operation upon the morning temperature data set.
- Separation of unsealed, vegetationless areas performing a ML - Classification.
- Remaining pixels are mostly building areas.

5. CONCLUSION AND OUTLOOK

The results of the different analysis methods allow the following conclusions:

- Transformation and calibration from NDVI sealing degree value is a less costly method to produce sealing maps and deliver sufficiently good results.
- The evaluation of soil sealing causes some unexpected problems using the temperature characteristics of urban surface materials. In general, sealed areas are characterized by a great heating at day time, a strong cooling at night. Surface temperatures are highly dependent on material. Partly temperature values of sealed areas are similar to values of trees, whose tops show unexpected high values.
  It has not yet been reached to separate sealed and unsealed areas completely by transforming data in an index, though separation of traffic areas is possible.
- The land-use classification does not deliver a quantitative registration of sealing degree values but differentiates surface cover types. The most important types such as grass, meadow, trees/shrubs and water can be classified exactly. More difficulties appear when classifying buildings because of their immense variation in roof materials. In this case it is necessary to classify each roof material which is costly, and, finally, to merge it into a "building class". Partly a spectral overlap of the classes "traffic area" and "building" is noticeable.
- Incorrectness of rectification cause severe problems in the multitemporal classification. Not at last for this reason it would be desirable for future projects to rectify using the exact positions of flight track.

The different sealing maps shall be controlled by means of reference material. Therefore it is planned to overlay a building layer obtained by a topographical map (1 : 10 000) and to determine the classification error for the "building" class. Furthermore, the produced maps need to be examined with sealing degree values checked in the terrestrial test sites.

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