APPLICATIONS OF MULTITEMPORAL AND MULTISENSORAL REMOTE SENSING DATA FOR MONITORING ASPECTS IN THE EAST GERMAN OPENCAST LIGNITE MINING AND POST MINING LANDSCAPES

Horst Weichelt, Monika Pilarski, Karsten Schmidt, Eberhard Jung, Karl-Heinz Marek
uve Remote Sensing Centre Potsdam, Germany

Kommission VII, Working Group V

KEY WORDS: Remote_Sensing, Environment, Monitoring, Vegetation, Land_Use, Multitemporal, Multisensoral

ABSTRACT

Investigations in connection with the generation of a remote sensing based monitoring system for ecological impact regions are presented for a postmining landscape. Concerning the practical use of such a monitoring system three tasks have been defined to deal with the vegetation changes in the surroundings and the dump areas of opencast lignite mines. Important problems in connection with the monitoring resulted from the need to normalize data taken at different acquisition times and sensor systems. Utilizing multitemporal data analysis and integration of terrestrial ancillary data the determination of the investigated processes on land use changes, renaturation and recultivation could be demonstrated.

KURZFASSUNG

Es werden Untersuchungen im Zusammenhang mit dem Aufbau eines fernerkundungsgestützten Monitoringsystems für ökologische Problemgebiete am Beispiel einer Bergbaufolgelandschaft vorgestellt. Dazu wurden drei Aufgabenbereiche für den Einsatz eines solchen Monitoringsystems formuliert, die jeweils die Vegetationsveränderungen in der Tagebauumgebung und auf den Kippenflächen betreffen. Wesentliche Probleme ergaben sich aus der für das Monitoring erforderlichen Normierung der Daten unterschiedlicher Erfassungszeitpunkte und unterschiedlicher Aufnahmesysteme. Unter Nutzung multitemporaler Datenanalysen und der Einbeziehung terrestrischer Zusatzdaten konnte die Erfaßbarkeit für die untersuchten Prozesse der Nutzungsänderung, Renaturierung und Rekultivierung gezeigt werden.

1 PROBLEM

Monitoring effects and processes which are linked to the human impact upon nature is of major importance due to the intensity of this impact in modern society. Even the technologies which are presently available enable remote sensing to contribute significantly to describe effects of the impacts of such processes ranging in particular from regional to global dimensions. In this context landscape changes caused by mining activities belong to the interesting regional processes. Especially opencast mines are characterized by relatively large displacements of excavation masses, lowering of ground water table in whole regions by as much as 100m and more, upbuilding of dumps of 60 to 80m thickness, creation of lakes due to rest hole floodings and changes of infrastructure caused by large scale deviations of transport communications, power lines and river courses. Anthropogenically used by the mining industry and therefore completely changed, these large areas require extensive measures for recultivation and new formation of landscapes which are going to be carried out in a reasonable scope.

In this context in Lusatia, East Germany, with its intensive lignite mining industry operated in opencast technology, a number of investigations have been performed on utilizing remote sensing for the determination and monitoring of the processes which are deterministic or influenced by anthropogenic factors.

The goal of all these single investigations is the creation of fundamentals for a regional environment monitoring system which shall comprise as an important constituent the analysis of satellite imagery based on currently available modern remote sensing systems (SPOT, Landsat-Thematic Mapper, ERS-1, high spatial resolution space photographs from russian space cameras) but also for the near future newly expected sensors, e.g. those ones to be installed on the module PRIRODA of the russian space station MIR. The main emphasis of the investigations is laid upon:

- determination of land use changes in opencast lignite mines and post mining landscapes
- determination of vegetation changes resulted from progessive mining activities
- monitoring of recultivation processes on dumps.

The work presented here refers to the Lusatian lignite mining region, an overview of which is given by Fig. 1, also indicating the selected investigation areas. The Lusatian lignite mining region is situated about 110km SSE from Berlin and is adjoined in the east by the state frontier to Poland. The east- west extension is about 80km, in north-south direction the distance amounts to 60km.

Concerning the natural units the region can be classified as older moraine landscape which is characterized by the paragenesis of moderately to strongly oversanded ground moraines covered by end moraines and aggregated aprons as well as by low moors. Since 1850 there had been traditionally significant changes of the landscape in connection with the ever growing extraction of raw lignite. The investigation area totals 17 major opencast mines, six of which are still in operation. The state of recultivation of these mines has progressed differently.

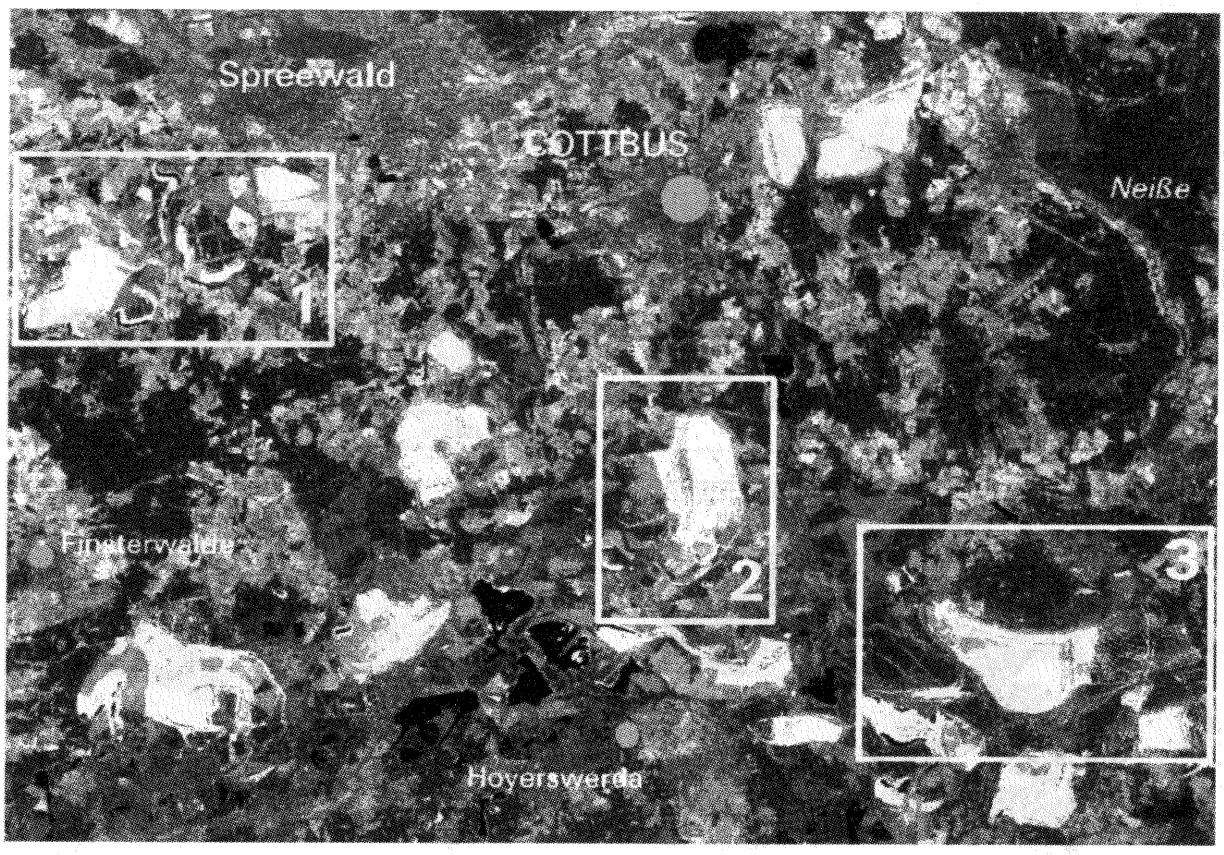

Fig. 1: Overview of the opencast lignite mining region of Lusatia and investigation areas: 1 - Schlabendorf, 2 - Welzow-Süd, 3 - Nochten (Landsat-TM, band 5, August, 9, 1992), scale approx. 1 : 450 000

2 VEGETATION AND LAND USE CHANGES IN OPENCAST MINE SURROUNDINGS

The investigation area of Nochten (see frame 3 in Fig. 1), which was named after the active opencast mine, is situated in the south-eastern region of Lower Lusatia extending about 40km in length and 20km in width. For this area a monitoring system is developed using tools of digital image processing and GIS, and whose main component consists of annually quantitative and qualitative analyses of multispectral satellite imagery. The investigations have focused on 33.000 hectares full covered biotopes mapped by field survey. Defined as habitats for plants, animals and biotic communities, they reflect both the complex site specific conditions and the anthropogenic influences. Within the investigation area the latter ones have resulted from progessive mining activities and, in connection to that, the effect of spatially extending ground water lowering. Features of vegetation like the predominating species composition create the criteria for mapping and categorization into 25 main categories.

Special aspects in monitoring systems to be developed are directed to the detection of vegetation changes brought about by the mining industry. In order to determine the influence of ground water lowering on the habitat development, it is necessary to derive the general long-term trend of vegetation development in the whole region which is influenced by the annual course of precipitation and temperatures. For estimating this trend Landsat-TM imagery, available since 1988 rather permanently, have been used. Additional three years field investigations made on reference biotopes, which are located beyond the impact zone of the opencast mines, shall determine deviations between these biotopes compared to those ones within the impact zone.

Since vegetation period 1995 research work on this issue have been carried out. The following results presented here are concerned with vegetation development observed at four acquisition dates during 1988 and 1995. For the analysis on wooded areas, which could be assumed to be completely covered by vegetation, the Normalized Difference Vegetation Index (NDVI) turned out to be a suitable measure. Its application on Landsat-TM data has been well proved for a long time. The biotope categories *nado-callunetea* and *sedo-scleranthetea* which can be anticipated with greater parts of uncovered soil were treated with the Modified Soil Adjusted Vegetation Index (MSAVI2) introduced by Qi et al. (1994). First statistical analyses on single biotopes have confirmed the conclusions derived by Qi et al., that MSAVI2 has a greater dynamic range, thus leading to always higher average values compared to the NDVI ones for the month considered (August). More special investigations on terrestrial reference areas with different vegetation cover degrees are planned. The processing of the NDVI values derived from pine forest biotopes have been realized by scaling the values into nine classes. This resulted in spectral feature distributions

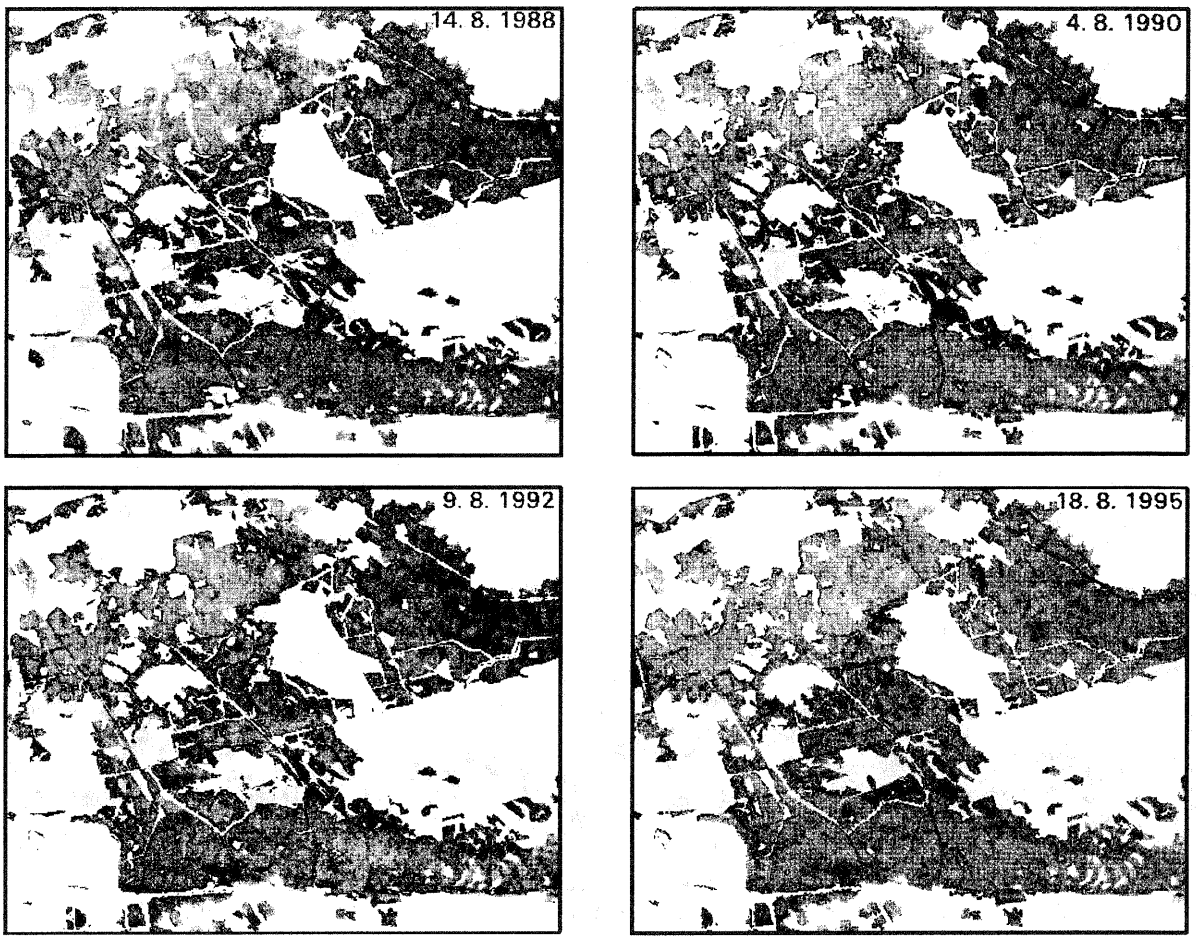

Fig. 2: Time series of scaled NDVI-values of pine forest biotopes in the surroundings of the opencast mine of Nochten

which are shown in Fig. 2. The visual impression, according to which the highest values of NDVI have been found in 1990 and 1995 while 1992 standed for the lowest ones, could be proved by statistical analyses (Fig. 3). More comparing investigations between the reference biotopes and those ones in the opencast mining impact zones are carried out during the vegetation period of 1996.

With exception of the low values found in 1992, the mean NDVI values from both, single pine forest types and total area clearly indicated an increase of vitality for the time period considered (1988-1995). The main reason for this

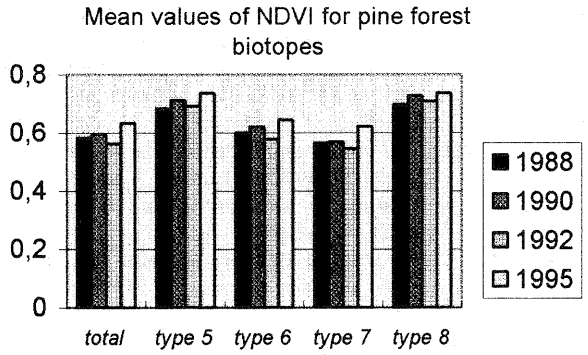

Fig. 3: Monitoring of vegetation for different pine forest biotopes in the area of Nochten

was due to the meteorological situation. Owing to great precipitation deficits during spring and summer 1992, it explains also the lower NDVI values. Because of the deindustrialization and reinforced protection measures against pollution, extreme declines in dust and sulphur dioxid emissions were observed (between 60% and 90%) which also proved to be important for the vegetation changes.

3 VEGETATION CHANGES ON SUCCESSION AREAS

Parallel to the preservation of nearly natural landscapes with high biotope and species diversity like, for instance, pine-moor forest and nado-callunetea in the surroundings of opencast mines, it is of interest, to utilize the specific site conditions which are characteristic to open post mining areas for a natural development. For such areas of renaturation which have been abandoned to natural succession, 15% of the dump areas are planned to get this status after closing of the mining activities. Such processes of natural settlement have been observed both by high spatial resolution satellite data and by field work on vegetation to serve as input for monitoring systems.

The investigation area selected has been the former opencast mine of Schlabendorf (see frame 1 in Fig. 1), whose northern part was closed in 1977. 1640 hectares out of 2490 hectares excavated area were given back to agriculture. 717 hectares were reforested and 133 hecta-

res can be ascribed to other use. In particular the so-called rest holes belong to the last category of areas which resulted from huge mass deficits by coal extraction and excavation technology. The re-increase of ground water table has filled up the holes. The lateral zones of the rest holes, and especially those ones of the hole F (Fig. 4), where sedimentation processes are still under way, have been selected and preserved, beside others, as natural succession areas. Another reason for this decision is the fact, that these rest holes can not be used for recreation purposes. Similar renaturation areas were also selected in the southern part of the opencast mine. As the closure of the mine took place only in 1991, the natural succession in this part have begun substantially later. According to the above mentioned goal of efficient environment monitoring for renaturation processes in post mining landscapes, appropriate test areas were selected in the rest hole peripheral zones after botanic viewpoints. These areas can be described as so-called pioneer settling communities in the form of:

- silver grass-*festuco-brometea*
- grass and herbaceous plants
- reed areas and
- dumps covered with dense moss.

An aerial photograph taken in June 1995 confirmed the assumption made in preparatory investigations, that the vegetation categories could be differentiated by CIR imagery. As no high spatial resolution satellite photographs from the cameras KFA-1000 respectively KWR-1000 were available in 1995, aerial photographs were used to simulate suitable data sets with a spatial resolution of 2m. For comparing purposes merged panchromatic and multispectral SPOT data with a final resolution of 10m were investigated (Fig. 4). It was demonstrated, that in case of the high resolution satellite data four categories of vegetation could still be discerned. The SPOT data set, on the other hand, permitted only a discrimination between vegetation and uncovered soil without being able to further differentiate single vegetation categories. Matching the interpretation results for succession areas obtained by the simulated satellite data with a ground truth botanic survey, more detailed parameters can be derived for the running renaturation process.

4 RECULTIVATION PROCESSES

Determination and supervision of recultivation processes of opencast mine dumps require in particular the observation of vegetation development. Depending on dump soil quality, which is linked to the soil material deposited by a special conveying bridge, and the follow-up measures aimed at physico-chemical soil amelioration, the dump areas are prepared for agricultural and forestal usage or for landscaping measures (wetland habitats, slope stabilization) as well. For monitoring recultivation processes it is necessary to determine the object category of the areas, their state

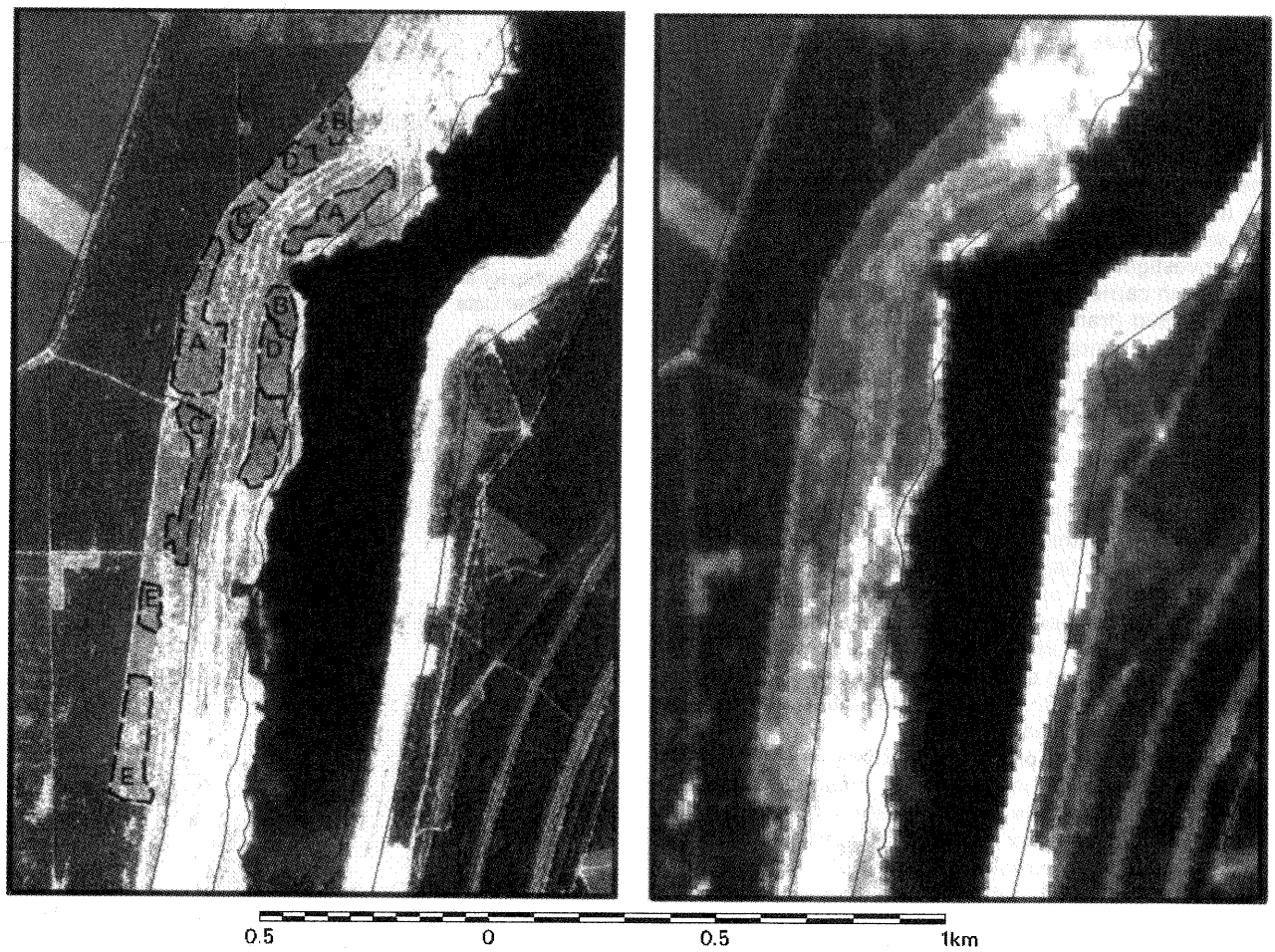

Fig. 4: Comparision between high spatial resolution satellite data for the determination of succession areas in the region of Schlabendorf, left: simulated KWR 1000, resolution 2m, right: SPOT XP+XS, resolution 10m

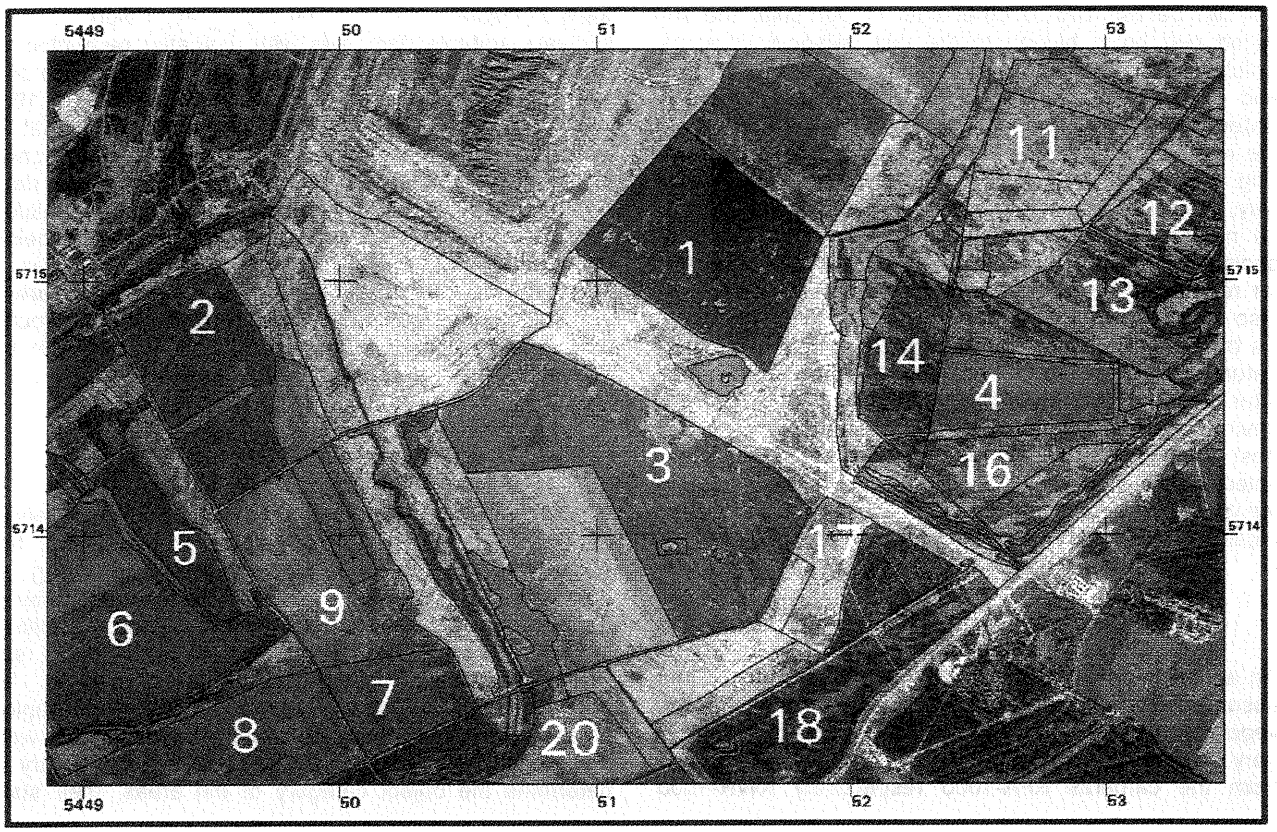

Fig. 5: General view of recultivated areas of the opencast mine Welzow-Süd (mosaic of aerial photographs taken by the camera AFA-41, 08. 10. 1993), scale 1 : 25 000

and degree of homogeneity during their temporal development. Furthermore it is of interest to determine the planned and undesired moist and wet spots as well as the soil moisture and substrate distribution for areas still without vegetation cover.

The investigations on monitoring recultivation processes have been carried out in the area of the opencast mine of Welzow-Süd (frame 2 in Fig. 1). The annual coal output of this mine amounts to about 26 Mio tonnes of lignite requiring approximately 200 Mio tonnes of stripping material to be removed. As a result dump areas of several thousand hectares have emerged. Fig. 5 shows part of the dump with recultivation zones of different land use.

In order to investigate the feasible contribution of remote sensing on monitoring recultivation processes remotely sensed features based on multisensor data have been derived (Fig. 6). For description of the recultivation parameters to be searched for, combinations of these remotely sensed derived features including ancillary data (expertises on dump soil, recultivation planning, meteorological data, field survey of land use classes) have been applied and processed.

One precondition of process monitoring is the multitemporal approach. The investigations presented here were carried out on available satellite imagery taken from 1991 to 1995, comprising six Landsat TM scenes, one SPOT-XS scene and two airborne scanner data sets (MSU-M). Parallel to the visible data airborne thermal scanner and SAR sensors were used to create multisensor data sets thus enabling simultaneous data processing and analysis to be performed during the acquisition times.

To attain comparability with the aim of deriving trends the data had to be normalized and eliminated from overlaying disturbing effects. Such a normalization procedure

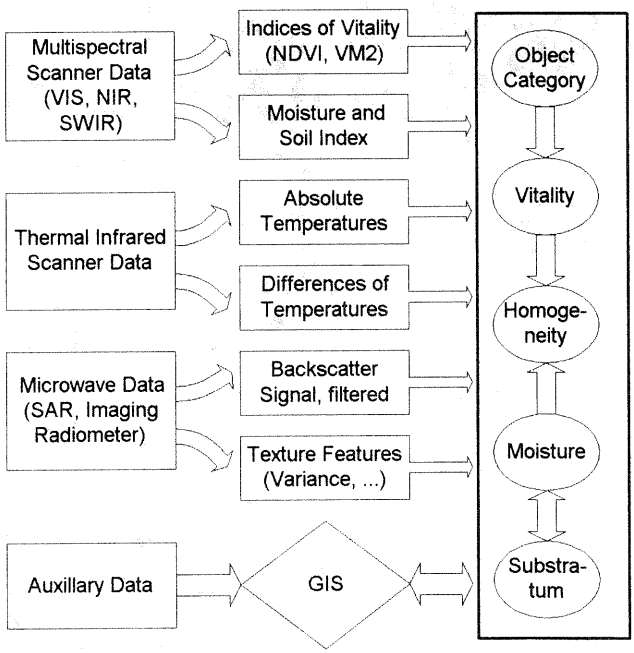

Fig. 6: Scheme of relationships between remotely sensed data and recultivation features (VM2: 'Spectral Curvature Index', after Weichelt et al., 1987)

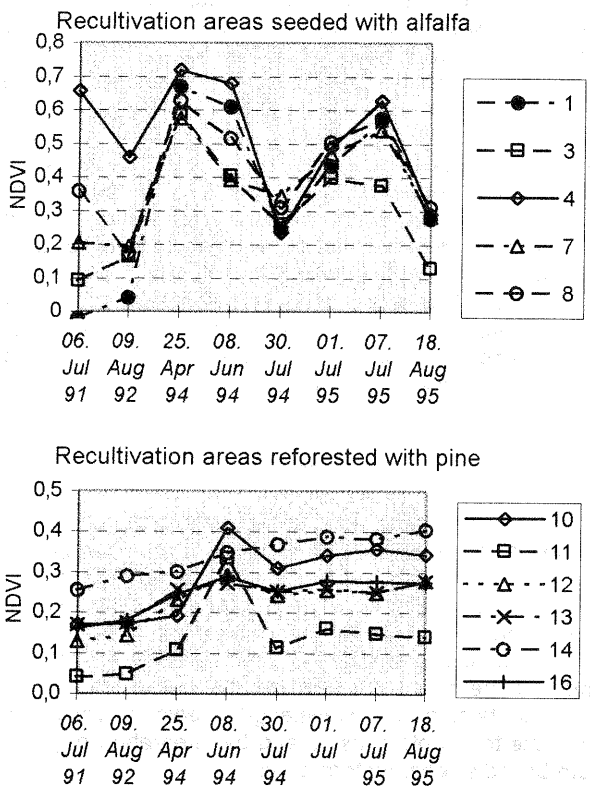

Fig. 7a,b: NDVI-development of selected recultivation areas (area numbers see Fig. 2)

has to be made inherently to the different categories of data and must consider the actual physico-geographical conditions. Though the formation of indices has already led to a certain amount of normalization, systematic discrepancies have been found by both sensor inherent as well as seasonal and annual specific influences. Therefore data normalization was performed on the basis of reference areas. Because of their relative stability 10 pine forest stands located in the surroundings of the opencast mine were selected. As examples, Fig. 7a and b show some appropriately corrected mean values of the NDVI for selected cropland and reforested areas.

It can be demonstrated that the agricultural areas cultivated with alfalfa have followed a typical annual variation which must be considered appropriately in trend analysis. Furthermore strong and area independent variations of vitality have been detected during the vegetation stages in summer which resulted from different kinds of agricultural treatments, e.g. harvest, of the areas at different times. In general, those kinds of variations do not exist for pine reforested areas. However, young pine trees which are still in development can undergo a strongly short-term increase of vitality during the end of May/begin of June, which is linked to fresh may sprouts (area numbers 10, 11). If an increase of vitality can be detected over a longer time period in spring and summer, then it can be ascribed to weeds and scrubs growing on the area.

Based on the corrected data of the areas mid- and short-term trends can be derived permitting an assessment of the development of the area concerned to be made during a certain time period. Table 1 shows the data for the recultivated areas of the Welzow-Süd dump from 1991 to 1995. Comparing the results between cropland and reforested areas, significant differences have been detected.

Area No.	Absolute values 7/91 NDVI	VM2	Trend 91-95 (per year) NDVI	VM2
1	- 0,02	0,77	+ 0,138	+ 0,502
2	0,348	2,24	- 0,016	- 0,091
3	0,091	0,98	+ 0,051	+ 0,139
4	0,658	6,60	- 0,050	- 0,401
5	0,606	5,68	- 0,013	- 0,390
6	0,491	3,26	+ 0,005	+ 0,030
7	0,206	1,36	+ 0,071	+ 0,316
8	0,358	2,08	+ 0,057	+ 0,294
9	0,068	0,96	+ 0,029	+ 0,020
10	0,171	1,27	+ 0,050	+ 0,172
11	0,041	0,88	+ 0,031	+ 0,046
12	0,129	1,16	+ 0,036	+ 0,085
13	0,170	1,32	+ 0,026	+ 0,055
14	0,256	1,71	+ 0,034	+ 0,172
15	0,136	1,18	+0,036	+ 0,087
16	0,162	1,28	+ 0,031	+ 0,083
17	0,090	0,99	+ 0,031	+ 0,065
18	0,258	1,73	+ 0,016	+ 0,051
19	0,236	1,56	+ 0,029	+ 0,132
20	0,124	1,09	+ 0,027	+ 0,061
21	0,347	2,29	+ 0,011	+ 0,031

Table 1: Vitality indices NDVI and VM2 for cropland areas (above) and reforested areas (below)

Depending on the start of the reforestation, the reforested areas have shown more or less a steady increase of vitality, indicating a corresponding continuous development of the plantations over several years, whereas the cropland areas cultivated with alfalfa can be described as very heterogenous. For area 1 which did not belong to the recultivation zone in 1991, a sharp increase of vitality can be observed from the start of cultivation. The same behaviour however was not found for the areas 2,4 and 5 which were already in recultivation in 1991. In these

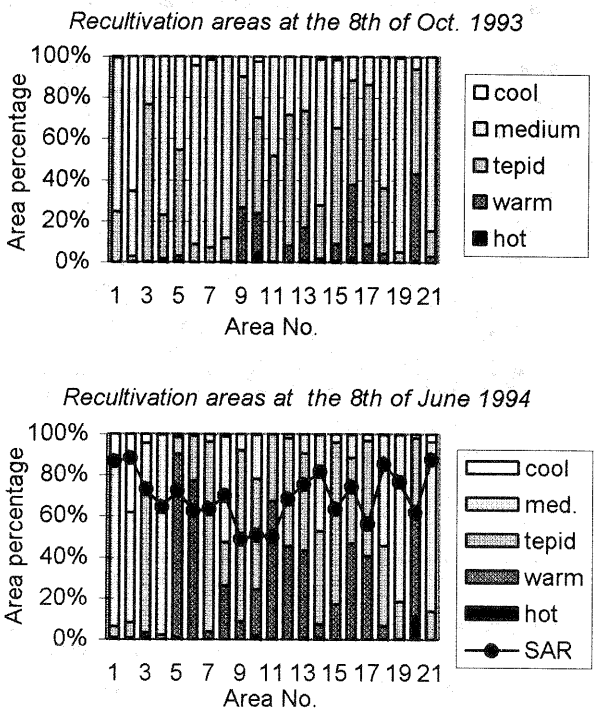

Fig. 8 a,b: Relative temperature distribution of recultivated areas, a: 1993, b: 1994

cases the vegetation states obviously depend only upon annual variations.
Due to the annual variations of temperature multitemporal analysis of thermal data can only be made by means of temperature differences. For this purpose the radiation signals measured by the TIR scanner were first transformed into temperatures values (brightness temperature of the black body) and then referenced to an average valuewhich is valid during the acquisition time. The relative difference to this average mean value was classified into six categories (Fig. 8a,b). The results of the thermal data analyses can be compared with the vitality features and give additional indications to the plant state. As a rule one can conclude that, the cooler a vegetation covered area is compared to its surroundings, the more dense and more vital it is. Concerning the alfalfa fields the different soil treatment measures have also to be considered. Based on the analysis of statistical distribution parameters, e.g. Pearson's coefficient of variation, conclusions on the homogenous development of the primary seeded areas can be derived. To this end both the variances of the vitality features, referred to the corresponding area, and the variances of the thermal and SAR data were computed. Areas 9,10,11 and 14 turned out to be especially inhomogenous. Corresponding fieldwork confirmed that just those areas suffered indeed from greater zones of deficiency or, in case of the pine reforestations, where sea buckthorn and robinia settled.
The SAR signatures shown in the plot for 1994 represent mean values per area of the relative backscatter coefficients which were obtained by the airborne SAR TRAVERS during the PRIRODA aircraft campaign 1994 (Marek et al., 1994). The SAR sensor operates at a wavelength of 10cm (S-band). From an alitude of 6000m it takes a swath width of 20km realizing a spatial resolution of approximately 20m by 20m. Unlike the thermal data the measured backscatter coefficients show only a slight correlation to the vitality coefficients. A strong relationship however is manifested to geometric plant features like plant growth height. For example, area 4 with weak backscattering was covered by plants with high vitality values but with plant heights of only 6-10cm. On the other hand, area 1 and 2 showed plants reaching heights of 40 to 50cm. The same is valid for the reforested areas. The highest backscatter values can be found on older trees with heights of 3m and more. Therefore a good discrimination is given for the unvegetated areas, which have been assigned to class 0-1 with lowest backscatter values. Based on that, additional conclusions, which have been independently derived compared to those ones on the vitality in the VIS region, can be drawn to describe the development of vegetation during the recultivation process. As a final step these results are transformed into a GIS where complex analysis with data from other sources can be made.

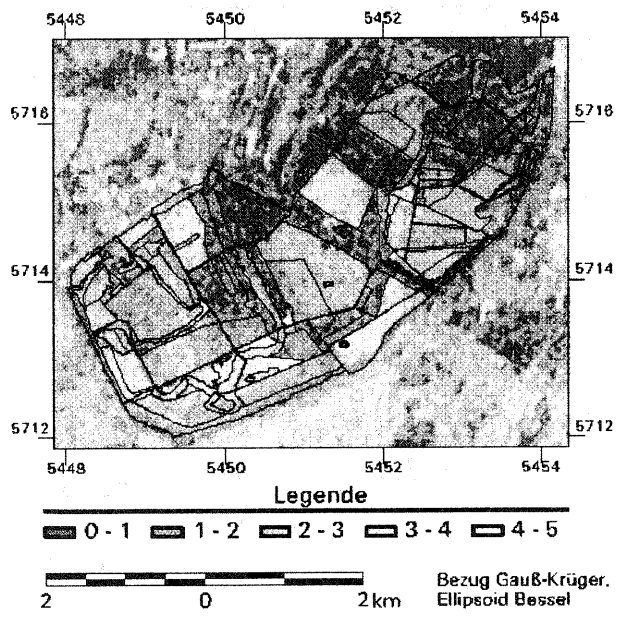

Fig. 9: Unsupervised classification of radar signatures of the recultivated areas of the Welzow-Süd dump

5 SUMMARY

Based on the presented complex analyses of remotely sensed data acquired at different times, monitoring tasks in ecological impact regions, like post mining landscapes, can be performed. The normalization of data and separation of the required information from other disturbing influences has turned out to be a basic problem. This can be overcome only by the use of multisensor data containing all wavelength regions which are available to remote sensing and by integration of ground truth based auxillary information.

The work presented here have been partially sponsored by the German Space Administration (DARA) and the Federal Ministry for Education, Science, Research and Technology (BMBF).

6 REFERENCES

Ahern, J. F, Leckie; D. J., Drieman, J. A.,1993. Seasonal Changes in Relative C-Band Backscatter of Northern Forest Cover Types. IEEE Transactions on geoscience and remote sensing, Vol.31, No.3, pp. 668-680.

Clevers, J.G.P.W., van Leeuwen, H.J.C., Verhoef, W., 1992. Estimating APAR by Means of Vegetation Indices: A Sensitivity Analysis. In: International Archives of Photogrammetry and Remote Sensing, Washington, D.C., Vol. XXIX, Part B7, pp. 691-698.

Marek, K.-H., 1992. Application of remote sensing data for the investigation of environmental degradation sites in East Germany. In: Proceedings of the Central Symposium of the 'International Space Year' Conference, Munich, Germany, Vol II, pp. 465-469.

Marek, K.-H., Weichelt, H., Kutuza, B., et al., 1994. Multi-Sensor Airborne Campaigns PRIRODA 1992-96 for Environmental Monitoring. In: Proceedings of the First Internat. Airborne Remote Sensing Conference, Strasbourg, France, Vol I, pp. 317-328

Qi, J., Chehbouni, A., Huete, A. R., et al., 1994. Modified Soil Adjusted Vegetation Index (MSAVI). Remote Sensing of Environment, 48, pp. 119-126.

Weichelt, H., Herr, W., 1987. Zur Vorverarbeitung multispektraler Daten. Vermessungstechnik, 33, pp. 270-272.