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Updating the Land Use and Land Cover Database CLC for the Year 2012 - „Backdating“of DLM-DE from the Reference Year 2009 to the Year 2006

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Updating the Land Use and Land Cover Database CLC for the Year 2012 - „Backdating“of DLM-DE from the Reference Year 2009 to the Year 2006

by

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Abstract

For the update of land cover according to CORINE Land Cover classes, a specific national approach has been chosen in Germany. This approach uses a more accurate geometry of the Official Topographical Cartographic Information System ATKIS of the land survey authorities. DLM-DE, derived from ATKIS, is to be applied as base for the deduction of CLC classes. In the responsibility of the German Federal Agency for Cartography and Geodesy (BKG), the DLM-DE 2009 database was built-up for the reference year 2009 with a minimum mapping unit (MMU) of 1 ha. Currently, an updated DLM-DE 2012 database is established by BKG; using methods of generalization this database will be transferred into the CLC2012 database (CORINE Land Cover 2012, having 25 ha MMU due to the EU specifications).

Besides CLC2012, a change layer of land cover between 2006 and 2012 is needed, describing the development of land cover categories (with 5 ha MMU). Due to the methodological modification, the change layer cannot be deduced directly by BKG using the conventional CLC2006 and DLM-DE 2012 or the resulting CLC2012. Direct changes can be achieved only by comparing DLM-DE 2009 and DLM-DE 2012 for the period from 2009 to 2012. Therefore, the task of DLR-DFD in this project was to model changes between 2006 and 2009 in the detailed geometry of DLM-DE 2009. Therefore, a database „CLC2006_Backdating” had to be created by a backward look from DLM-DE 2009 to the situation of land cover / land use in 2006. This has been done using an approach starting by the most common 46 change classes (based on the changes between 2000 and 2006). Using semi-automatic approaches such as segmentation and combined multi-seasonal and multi-sensoral data processing, changed parts of the polygons of DLM-DE 2009 were derived. Besides IMAGE2006 data, Landsat data, and AWiFS time series data of 2005 / 2006 were used in this project.

Kurzbeschreibung

Für die Aktualisierung der Landbedeckung / Landnutzung gemäß den CORINE Land Cover Klassen ist in Deutschland ein spezieller nationaler Weg eingeschlagen worden. Dabei sollen die wesentlich genauere Geometrie des Amtlichen Topographisch – Kartographischen Informationssystem (ATKIS) der Landesvermessungsverwaltungen und das daraus erstellte Digitale Landbedeckungsmodell für Deutschland DLM-DE als Grundlage für die Ableitung der CLC-Klassen genutzt werden. In der Verantwortung des Bundesamtes für Kartographie und Geodäsie (BKG) wurde hierzu im nationalen Kontext für das Referenzjahr 2009 die Datenbasis DLM-DE 2009 mit einer 1 ha Mindestkartierfläche (MKF) aufgebaut. Zurzeit wird eine aktualisierte Datenbasis des DLM-DE 2012 vom BKG erstellt; mittels Generalisierungsmethoden soll dieser in den Datensatz CLC2012 (CORINE Land Cover 2012 mit 25 ha MKF laut den EU-Spezifikationen) überführt werden.

Neben dem CLC2012 wird auch ein Änderungsdatensatz der Landnutzung und Landbedeckung zwischen 2006 und 2012 benötigt, der die Entwicklung der Landbedeckungskategorien beschreibt (mit MKF 5 ha). Aufgrund des Methodenwechsels kann der Änderungsdatensatz nicht direkt aus dem CLC2006 und dem DLM-DE 2012 bzw. dem resultierenden CLC2012 durch das BKG abgeleitet werden, direkte Änderungen resultieren nur aus dem Vergleich von DLM-DE 2009 und DLM-DE 2012 für den Zeitraum 2009 bis 2012. Daher war es Aufgabe des DLR-DFD in diesem Vorhaben, die Anteile der Änderungen zwischen 2006 und 2009, in der detaillierten Geometrie des DLM-DE 2009, zu modellieren. Dazu sollte ein Datensatz „CLC2006_Backdating“ durch eine „Rückschau“ des DLM-DE 2009 zurück auf die Situation der Landbedeckung in 2006 gewonnen werden. Dies geschah mit einem Ansatz, der von den häufigsten 46 Änderungsklassen (basierend auf den Änderungen zwischen 2000 und 2006) ausging. Mit semi-automatischen Methoden wie Segmentierungen und multi-saisonalen / multi-sensoralen Datenverknüpfungen wurden veränderte Teilflächen von DLM-DE 2009 ausgewiesen. Neben IMAGE2006 Daten kamen Landsat-Daten und AWiFS Zeitreihendaten von 2005 / 2006 zum Einsatz.

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Concerning the use of ortho-rectified IRS LISS-III products:

Concerning the use of ortho-rectified SPOT products:

Concerning IRS-P6 AWiFS products:

Concerning Landsat products:

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List of Abbreviations

ATCOR	Atmospheric Correction
ATKIS	„Amtliches Topographisch-Kartographisches Informationssystem“ – Official Topographical Cartographic Information System
AWiFS	Advanced Wide Field Sensor
BDLM	Basis-DLM
BKG	„Bundesamt für Kartographie und Geodäsie“ – German Federal Agency for Cartography and Geodesy
CLC	CORINE Land Cover
CMF	Cloud Mask File
DFD	„Deutsches Fernerkundungsdatenzentrum (DLR)“ – German Remote Sensing Data Center
DHDN	„Deutsches Hauptdreiecksnetz“
DLM-DE	„Digitales Landbedeckungsmodell – Deutschland“ – Digital Land Cover Model for Germany
DEM	Digital Elevation Model
DLR	„Deutsches Zentrum für Luft- und Raumfahrt (DLR)“ – German Aerospace Center
DLR-UID	DLR-User ID
DMC	Disaster Monitoring Constellation
EEA	European Environment Agency
EOC	Earth Observation Center
ESA	European Space Agency
ETM+	Enhanced Thematic Mapper plus
FTSP	Fast Track Service Precursor
GLOVIS	USGS Global Visualization Viewer
GMES	Global Monitoring for Environment and Security
GSE	GMES Service Element
Ha	Hectar
HRG	High Resolution Geometrical
HRL	High Resolution Layer
HRVIR	High Resolution Visible and Infrared
IMF	„Institut für Methodik der Fernerkundung (DLR)“ – Remote Sensing Technology Institute
IRS-P6	Indian Remote Sensing Satellite-P6
LISS-III	Linear Imaging Self-Scanning Sensor - 3
MDNWI	Modified Normalised Difference Water Index

MMU	Minimum Mapping Unit
NASA	National Aeronautics and Space Administration
NDVI	Normalised Difference Vegetation Index
NIR	Near Infrared
PAN	Panchromatic
SLC	Scan Line Correctors
SPOT	Satellite Pour l'Observation de la Terre
SRTM	Shuttle Radar Topographic Mission
SWIR	Short-wave Infrared
TIR	Thermal Infrared
TM	Thematic Mapper
UBA	„Umweltbundesamt“ – Federal Environment Agency
USGS	US Geological Survey
UTM	Universal Transverse Mercator
VIS	Visible
VIS-B	Visible Blue
VIS-G	Visible Green
VIS-R	Visible Red (
WGS-84	World Geodetic System 1984

1 Summary

1.1 Introduction and Objective

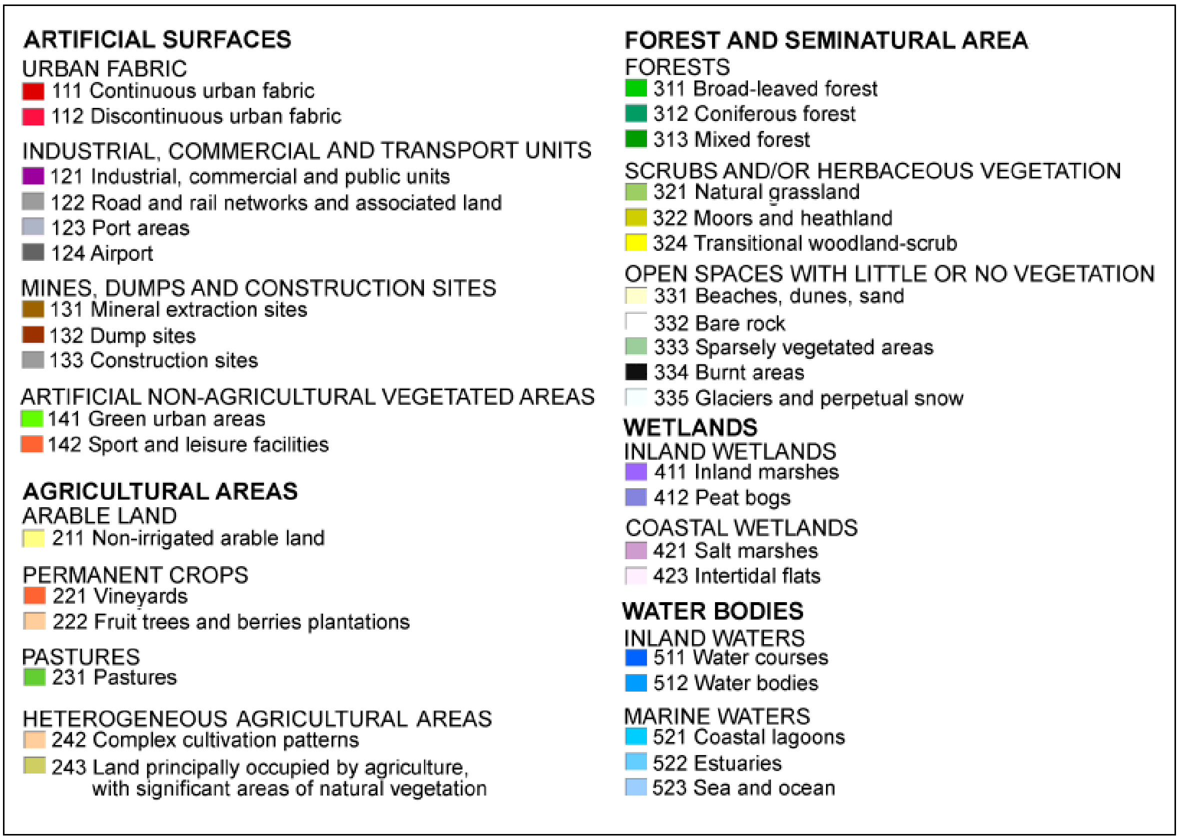
For the update of land cover according to CORINE Land Cover classes, a specific national approach has been chosen in Germany. This approach uses a more accurate geometry of the Official Topographical Cartographic Information System ATKIS of the land survey authorities. The "Digital Land Cover Model" DLM-DE, derived from ATKIS, is to be applied as base for the deduction of CLC classes. In the responsibility of the German Federal Agency for Cartography and Geodesy (BKG), the DLM-DE 2009 database was built-up for the reference year 2009 with a minimum mapping unit (MMU) of 1 ha. Currently, an updated database DLM-DE 2012 is established by BKG. Using methods of generalization, this database will be transferred into the CLC2012 database (CORINE Land Cover 2012, having 25 ha MMU due to the EU specifications). The adjustment of the update is conducted using satellite data of 2012.

Besides CLC2012, a change layer of land cover between 2006 and 2012 is needed which describes the development of land cover categories (with 5 ha MMU). The update of DLM-DE 2009 to the year 2012 grants only directly the deduction of changes between 2009 and 2012. A comparison of changes of the conventionally derived CLC2006 (with 25 ha MMU) with DLM-DE 2009 or DLM-DE 2012 would mainly yield differences because of different geometries. Therefore it was necessary to derive spatial information on the changes regarding the more detailed geometry of DLM-DE 2009.

The modelling of changes between 2006 and 2009 in the detailed geometry of DLM-DE 2009 was task of DLR`s German Remote Sensing Data Center (DFD). For that purpose, a database „CLC2006_backdating" had to be created by a „backward look" from DLM-DE 2009 to the situation of land cover / land use in 2006. This has been done using an approach including the 46 most common change classes (based on the changes between 2000 and 2006). As far as possible, automatic or semi-automatic methods were used.

The scheme of land cover classes due to CORINE Land Cover in Germany is presented in Figure 1.

Figure 1: Scheme of land cover classes due to CORINE Land Cover in Germany, including color coding



1.2 Data base

The available data base for the retrospective derivation of the land cover situation in 2006 consists of several vector data and satellite imagery products.

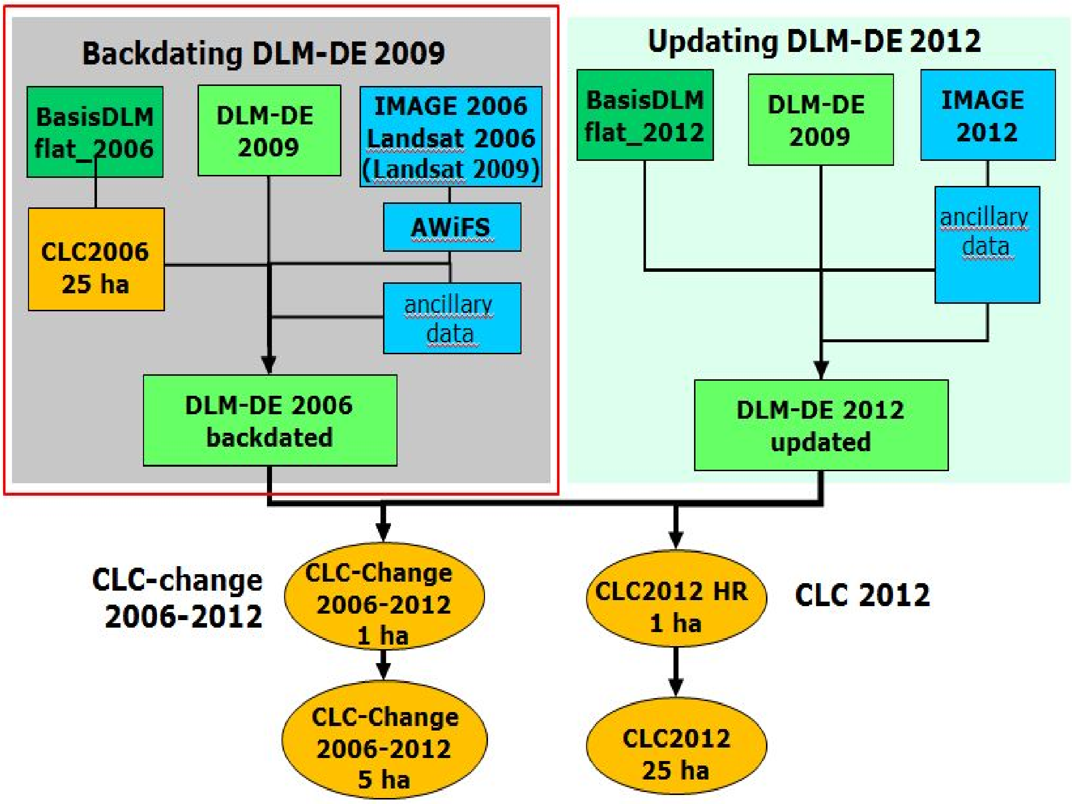
- **Digital Land Cover Model DLM-DE2009:** The database DLM-DE 2009 is based on the ATKIS Basis-DLM for the year 2009 which has been produced in responsibility of the BKG and checked and updated using various high resolution satellite imagery of the sensors RapidEye and DMC. DLM-DE 2009 was the base of „Backdating“, back to the year 2006.
- **ATKIS Basis-DLM Flat Layer 2006 Federal States:** The ATKIS Basis-DLM 2006 for all federal states was available in form of a prepared non-overlapping vector database, which was not checked and updated by satellite imagery. It was fixed to the status of spring / early summer 2006.
- **CORINE Land Cover 2006 (with 25 ha MMU):** The dataset of CLC2006 was used directly only for special situations because of the minimum mapping unit (MMU) of 25 ha. However, the dataset was applied for many comparison tasks.
- **Satellite imagery IMAGE2006 spring and summer:** From the conventional approach of CORINE Land Cover production, the satellite database IMAGE2006 was available and used for the Backdating tasks. It consists of satellite images from the IRS-P6 LISS-III and SPOT-4 HRVIR / Spot-5 HRG sensors for two seasonal coverages (spring and summer aspect).
- **Satellite imagery Landsat-5 summer:** Landsat-5 TM images covering entire Germany formed an additional homogeneous coverage in summer aspect for the year 2006. At the same time, the Landsat imagery built a backup input dataset in regions with restricted IMAGE2006 data availability caused by atmospheric conditions (high cloud cover).
- **Satellite imagery AWiFS 2005 / 2006 multi-seasonal:** During pre-studies, the high potential of multi-seasonal AWiFS imagery was proven concerning the differentiation between arable land and pasture land. The AWiFS data with a spatial resolution of about 60 m were used to derive indicators for the characterization of vegetation dynamics and for the separation between arable and grassland. The 43 AWiFS scenes for the multi-seasonal coverage of Germany were purchased by project funds.
- **Soil Sealing Layer 2006:** This information layer was provided by UBA and presents the built-up areas of the EEA member states, including the degree of soil sealing between 1% and 100%. The dataset exists in two versions and was derived from satellite imagery of the IMAGE2006 dataset. The primary version „EEA Fast Track Service Precursor – Degree of soil sealing“ includes built-up areas, mineral extraction sites, and still open construction sites. The version „Revised Soil Sealing 2006, degrees of sealing 20 m and 100 m“ had been completely revised in the FP7 project „geoland2” and does not include mineral extraction sites and open construction sites.
- **Regional available data:** For various regions of Germany, forest map products were available from the project „GSE Forest Monitoring“, which were produced under responsibility of the GAF AG.

Figure 2 shows a summing-up of data flows and working steps (as part of the whole project CLC2012). Two tasks can be identified: First, the updating for the description of CLC status in the year 2012; secondly, the backdating as part of the deduction of „CLC-Change“, including the changes between 2006 und 2012. The updating component (data flows on the right) was carried out by BKG as explained before.

1.3 Methods

Five different software packages were used: The processing system CATENA, developed by the DLR Remote Sensing Technology Institute, was deployed for various steps of pre-processing. The GIS software ESRI ArcGIS 10 was used for all GIS related steps. For image processing, ERDAS Imagine version 2011, eCognition Developer version 64 of Trimble company (particularly for image segmentation), and the „Interactive Description Language“ IDL (version 7.1 and 8.1) were used.

Figure 2: The two tasks of updating and backdating during the production of CLC2012 and CLC-change (2006 – 2012) showing also the related data flows. Source: BKG presentation at the kickoff meeting of „CLC Backdating" on 27 September 2012, modified.



Approach to assess primary change processes:

For backdating the DLM-DE2009 onto the situation of land cover in 2006, an approach was chosen which uses the most common 46 change classes (based on the changes between 2000 and 2006, assessed in CLC2006). The first eight change processes (composed by changes in forest composition because of storm damages, clearing and reforestation, transitions from grassland to arable land in agriculture, development of new settlements, industrial built-up and mineral extraction sites on arable land) already cover 51.2% of cumulated percentages of change areas (see Table 1). Taking into account the 46 most frequent change classes, a coverage of 89.7 % of the changed areas was given in CLC2006. By a suitable grouping of change classes it was initiated to refer on thematic raster layers for the reference year 2006 - e.g. a layer of mineral extraction sites, CLC class 131, to get the proportion in the polygons of DLM-DE2009 for the determination of changes. By segmentations of generally affected polygons, based on high resolution satellite data like in IMAGE2006, sub-areas in the change polygons were to be integrated.

Pre-processing steps:

Germany was divided into 6 working units – so called macro-regions - consisting of one or more federal states. Thus, macro-region BY contained the area of Bavaria, NW the area of North Rhine-Westphalia, Hesse, Rhineland-Palatinate, and Saarland. Prepared mosaics of IMAGE2006 coverages (spring and summer) for each macro-region and an additional dataset of Landsat summer data built the high resolution satellite data base. The preparation step of the mosaics included cloud and cloud shadow masking to define un-valid pixels.

Table 1: The dominating 8 change classes due to CLC changes between 2000 and 2006 in Germany

Legend:

Legend
Intensification in agriculture
Extensification in agriculture
Afforestation
Areas with forest loss
Urbanisation / Increase of soil sealing
New extraction sites
Recultivation of extraction sites
New water bodies
Other change

Range No.	Process	Germany		
		Area [km²]	Percentage	cumulated
1	312 → 324	265.30	11.77%	11.77%
2	231 → 211	192.87	8.56%	20.33%
3	211 → 112	178.61	7.92%	28.25%
4	324 → 313	157.95	7.01%	35.26%
5	324 → 312	117.93	5.23%	40.49%
6	211 → 131	86.09	3.82%	44.31%
7	133 → 112	77.81	3.45%	47.76%
8	211 → 121	77.21	3.43%	51.18%

As one main thematic information layer in agricultural areas, the multi-seasonal information of IRS-P6 AWiFS time series was to be integrated for the separation of arable and grassland areas. For this it was necessary to apply a co-registration of the AWiFS data, as well as a generation of multi-seasonal mosaics (e.g. for the months of April, May, July, and September) and a deduction of temporal statistics for AWiFS. The vegetation index NDVI („Normalized Difference Vegetation Index“) was used as an indicator for the description of vegetation development in the single objects along the year (the phenological characteristics). The temporal dynamics in the NDVI time series data contain valuable information concerning the probable affiliation to arable land or grassland. A set of parameters with minimum, maximum, mean, and standard deviation was used for that.

Derivation of thematic raster layer:

The derived thematic raster layers with the status of 2006 had partly the role of interim layers. These layers were also further processed using logical linking. On the other hand, the raster layers, such as the deduced layer of mineral extraction sites (CLC class 131) to the status of 2006, could directly be integrated to derive potential transitions of land cover (e.g. for the transition 131-> 512, mineral extraction site in 2006 to water body in 2009).

The following interim layers are to be named:

- Two variants of *„Soil Sealing Layer 2006“:* including and excluding mineral extraction sites and construction sites, information layer for extraction sites in 2006,
- *Built-up Layer 2006* from Basis-DLM_2006_flach (with high degree on currency), including at least one of the CLC-classes 111, 112 or 121,
- *Layer for forest cover 2006* (forest mask 2006) from Basis-DLM_2006_flach (also highly current concerning the outer limit of forest areas), with at least one of the forest classes in CLC showing 311, 312, 313, or 324.

By combinations of interim layers and satellite image products, or solely by products from satellite data, the following raster layers were deduced, which can be directly integrated in the land cover situation of 2006:

- *Water mask* (CLC 512), derived by combined threshold classifications from three deduced indices from the Landsat mosaics (NDVI, water index MNDWI due to Xu, SWIR band); the water class is not considered for potential change areas, but it is important for the manual checks (e. g. for mineral extraction sites or transitions in 2006);
- *Mineral extraction sites* (CLC 131), derived by a complex rule set using the two variants of soil sealing layer, the DLM-DE2009 database (potential later classes in 2009), CLC2006, and the single Landsat scenes of 2006;

- *Construction sites* (CLC133), derived by the two variants of soil sealing layer, with an additional rule on membership to at least one of the classes in DLM-DE2009: 133, 111,112,121, or 122;
- *Arable areas* (CLC 211), delineation by a combination of thresholds for the temporal statistics results of the AWiFS based NDVI time series, and exclusion of built-up areas, forest areas, and water areas in 2006;
- *Grassland areas* (CLC 231, partly also CLC 321), in addition delineation by a combination of thresholds for the temporal statistics results of the AWiFS based NDVI time series, and exclusion of built-up areas, forest areas, and water areas in 2006, and also other areas;
- *Forest distribution concerning the forest classes* (CLC 311, 312, 313, 324); diversification within the forest mask 2006, use of CLC2006, determination of detailed distribution of forest areas with status 324 in DLM-DE2009 and (still) 312 in 2006 or (already) 324 in 2006 by using IMAGE2006 and Landsat based information, especially in the SWIR bands;
- *Only regional distributed land cover classes* (CLC 222, 321, 331, 333), with the initial situation deduced by CLC2006, partly adapted by manual improvements.

Integrating the information from DLM-DE2009, satellite imagery 2006 and raster layers 2006:

The 12 thematic raster layers keep the thematic information on land cover / land use in the status of 2006 and correspond with one of the CLC classes (see before). They determine the participating classes for 2006 concerning the main changes and their spatial distribution. For modelling the backdating dataset, the following further tasks had to be performed:

- Derivation of polygons which are potentially affected by changes in the geometric skeleton of DLM-DE2009 (calculation of zonal statistics);
- Determination of polygons which show a complete (or by high dominance) transition to another CLC class in 2006 (calculation of zonal statistics);
- Sub-segmentation of polygons which are partly affected by changes between 2006 and 2009; the segmentation used suitable high resolution satellite data in form of the three mosaics "summer aspect LISS-III" including cloud and cloud shadow masks, „spring aspect LISS-III" including cloud & cloud shadow masks, and „summer aspect Landsat-5 Thematic Mapper" with cloud masks;
- Allocation of the dominant CLC classes due to the thematic raster layers as class members in the selected sub-segments (using zonal statistics assessment) and output of the change polygons.

The work flow including the data flow is presented in the overview graph in Figure 3.

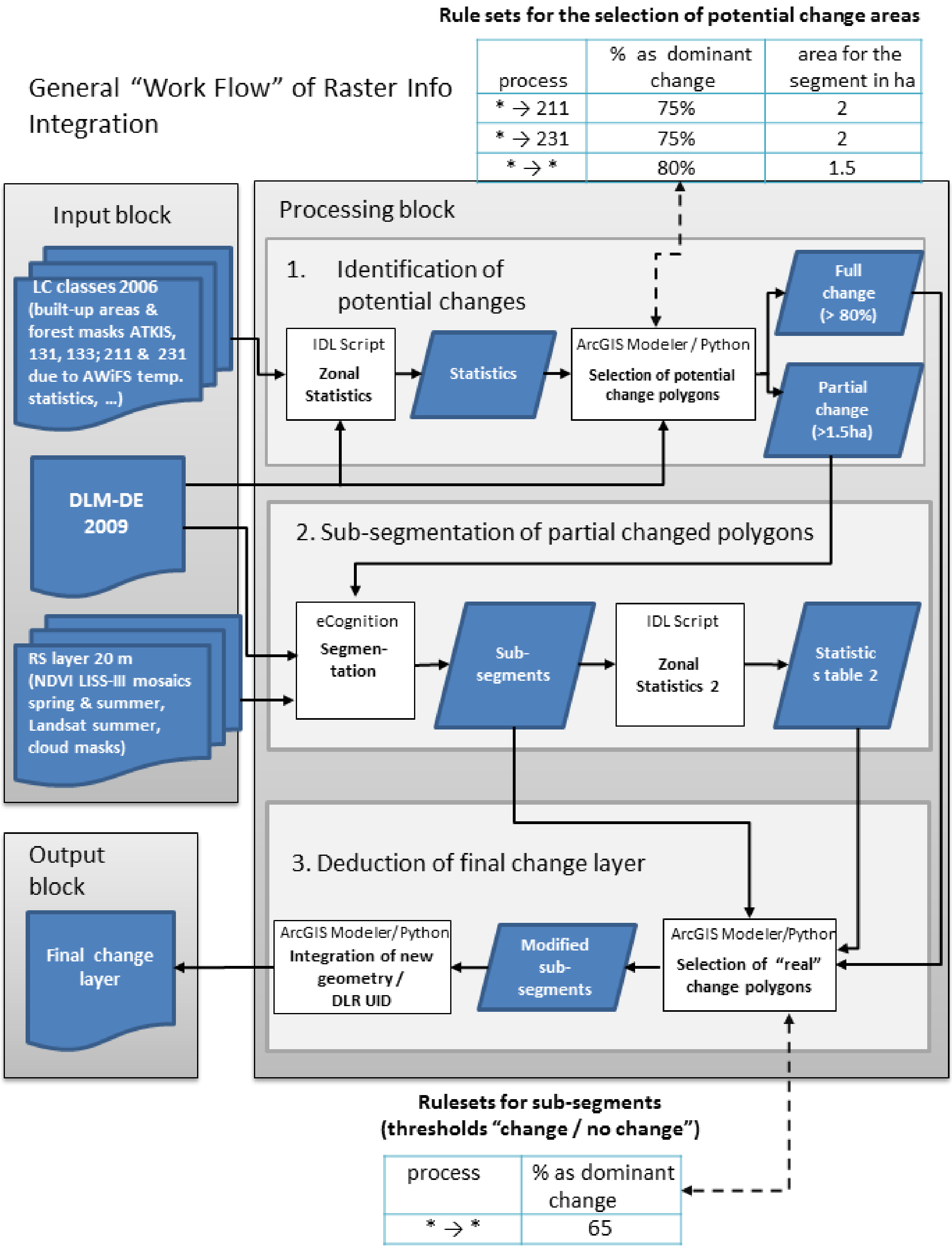
Plausibility checks and improvement of change polygons:

The determined polygons which showed a change in comparison to 2009 were investigated by a number of plausibility checks. The results were first noted in additional attributes. Before thematic inspections, checks were done for polygons with an area below 0,5 ha and 1,0 ha, respectively, followed by form parameter checks to identify small objects. These polygons were not included in the plausibility checks, but were marked and still available for later tasks in the context of complex change areas. As one example, the checks for potential changes from arable land / pasture land (CLC classes 211 and 231) to recreation and sports areas (CLC class 142) are mentioned here. CLC-class 142 is not covered by the built-up area mask or the forest mask. Thus, class 142 is included in the classification of arable and pasture land for 2006. Most indicated changes are not real changes. But a check is necessary to identify changes from arable land or pasture land to new golf courts which are part of CLC class 142.

1.4 Resulting Products

The resulting products of single macro-regions or sub-units were successively delivered to the BKG for further data integration. For each region, two final products were generated: A set of improved change polygons (with change areas larger than 1 ha) for the period between 2006 and 2009, and the resulting retrospective land cover situation in 2006, integrated in the CLC2006_Backdating database, with 1 ha minimum mapping unit.

Figure 3: Work flow during the integration of satellite imagery, thematic raster layers and the input data of DLM-DE 2009 vector database



1.5 Considerations on Data Quality

For the indicated changes in agricultural areas, full-cover checks of the contribution to arable land or pasture land were necessary. Due to time limits, the checks had to be done on scales ranging from 1:30,000 to 1:40,000. Together with the multi-seasonal AWiFS indication, also the combination of visual inspection of the three high resolution satellite mosaics was considered for the decision if polygons had to be marked with change or no change. In several situations, the AWiFS indicators were disturbed, e. g. in riparian zones by temporal flooding states, and indicated wrong changes then.

In addition, the deduced statistical parameters (like minimum, mean, standard deviation) were depending on the representativeness of available acquisition times in the AWiFS scenes and on local gap-free or gap-disturbed coverage by 4 up to 7 scenes. In the combined use of AWiFS indicators and the three mosaic variants of LISS-III and Landsat products, an essential improvement of allocation to real and non-real changes in agriculture was possible. It can be assumed that the multi-seasonal coverage can be optimized in future, e. g. by time series of the future Sentinel-2 system, thus also improving the automatic arable land / pasture land separation.

An area-wide check of indicated change polygons was also performed concerning changes in forest areas and transformation processes in areas surrounding mineral extraction sites. For other change types, first the largest change polygons per change combination were checked, followed by checks on smaller polygons. Partly, this approach was combined by area-wide checks in regions with indications of false change contributions and in “hot spots” of changes.

1.6 Conclusion

In the project, a semi-automated approach was used for derivation of land cover changes, based on 46 change classes which were indicated to cover about 90% of change areas. The applied method was proven to be a feasible approach, delivering satisfying results. However, a quite large amount of pre-processing was connected with this, especially regarding various satellite image mosaics, and also the checks and manual improvements of the automatically detected change polygons reached a higher extent in relation to the estimates from the beginning. With respect to the large data volume of the DLM-DE vector database with 1 ha MMU, it should be remarked that an effective pre-selection of potential change polygons and a manageable segmentation were crucial steps during the project progress.

With an improved multi-seasonal database in the upcoming Sentinel-2 era, there will be an improved multi-seasonal coverage for analyses in the field of agriculture. Altogether, a similar semi-automated approach is also conceivable in the context of a forward-looking update of a land cover database by applying available vector geometries.

2 Zusammenfassung

2.1 Einführung und Zielsetzung

Zur Aktualisierung der Landbedeckung / Landnutzung gemäß den CORINE Land Cover Klassen wurde in Deutschland seit 2008 ein spezieller nationaler Weg eingeschlagen. Dabei sollen die wesentlich genauere Geometrie des Amtlichen Topographisch – Kartographischen Informationssystem (ATKIS) der Landesvermessungsverwaltungen und das daraus erstellte Digitale Landbedeckungsmodell für Deutschland DLM-DE als Grundlage für die Ableitung der CLC-Klassen genutzt werden. In der Verantwortung des Bundesamtes für Kartographie und Geodäsie (BKG) wurde hierzu im nationalen Kontext für das Referenzjahr 2009 die Datenbasis DLM-DE 2009 mit einer 1 ha Mindestkartierfläche (MKF) aufgebaut. Zurzeit wird eine aktualisierte Datenbasis des DLM-DE 2012 vom BKG generiert. Diese soll mittels Generalisierungsmethoden in den Datensatz CLC2012 (CORINE Land Cover 2012 mit 25 ha MKF laut den EU-Spezifikationen) überführt werden. Der Abgleich der Aktualisierung wird mit Satellitendaten von 2012 erstellt.

Neben CLC2012 wird auch ein Änderungsdatensatz der Landnutzung und Landbedeckung zwischen 2006 und 2012 benötigt, der die Entwicklung der Landbedeckungskategorien beschreibt (mit MKF 5 ha). Die Aktualisierung des DLM-DE 2009 zum Jahr 2012 am BKG lässt unmittelbar nur eine Ableitung der Änderungen zwischen 2009 und 2012 zu. Ein Vergleich des herkömmlich abgeleiteten CLC2006 (mit 25 ha MKF) und der Datenbasis DLM-DE 2009 oder auch DLM-DE 2012 hinsichtlich der Änderungen wird vor allem Unterschiede hinsichtlich der unterschiedlichen Geometrien ergeben. Daher ist es notwendig, Aussagen zu den Änderungen bezogen auf die feinere Geometrie von DLM-DE 2009 zu treffen.

Die Modellierung der Anteile der Änderungen zwischen 2006 und 2009 in der detaillierten Geometrie der Datenbasis DLM-DE 2009 war die Aufgabe des DLR-DFD. Dazu sollte durch eine Rückdatierung des DLM-DE 2009, ein sogenanntes „Backdating“, auf die Situation der Landbedeckung in 2006 ein Datensatz „CLC2006_Backdating“ gewonnen werden. Dies geschah mittels eines Ansatzes, der von den häufigsten 46 Änderungsklassen, basierend auf den ermittelten Änderungen zwischen 2000 und 2006, ausging. Dabei sollten nach Möglichkeit zu einem größeren Teil automatische bzw. semi-automatische Methoden zum Einsatz kommen.

Das Schema der Landbedeckungsklassen gemäß CORINE Land Cover für Deutschland ist in Figure 4 dargestellt.

2.2 Datenbasis

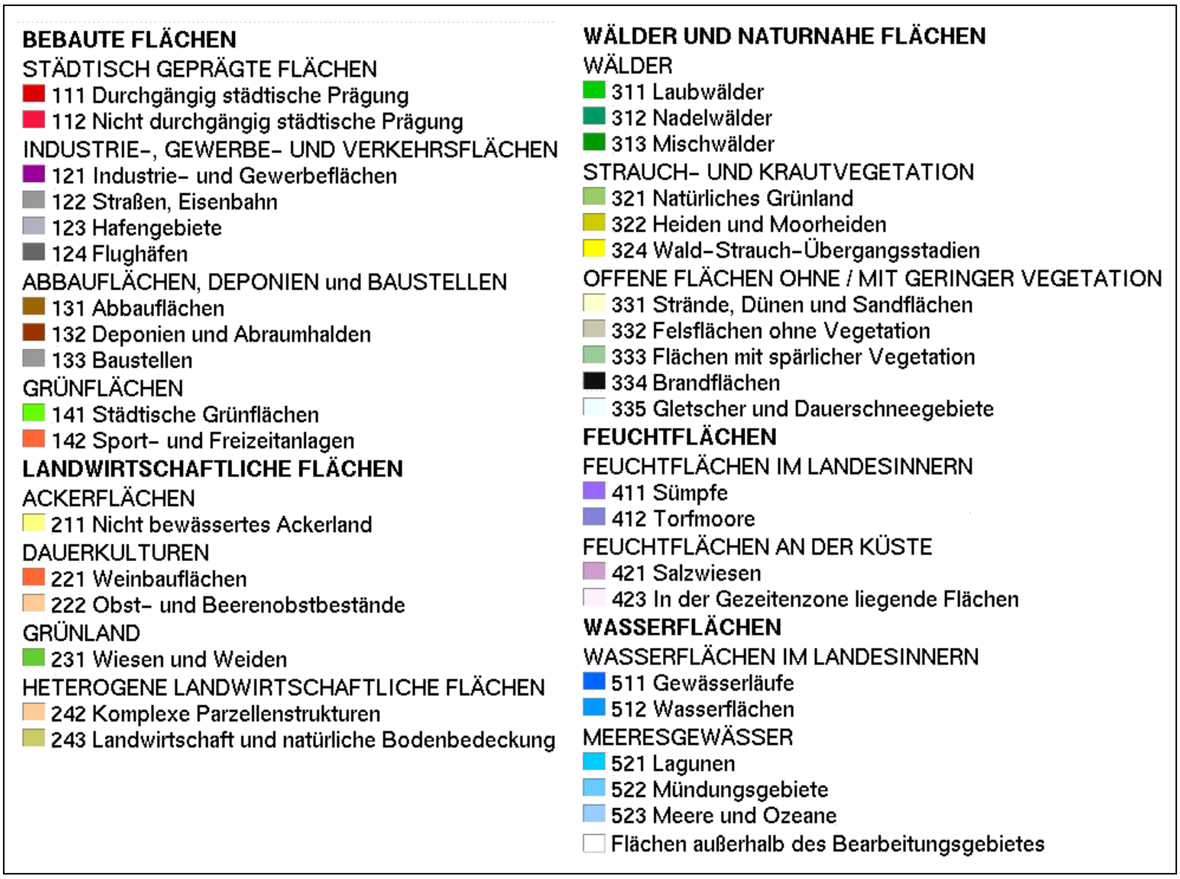
Die zur Verfügung stehende Datenbasis für die retrospektive Ableitung der Landbedeckungssituation in 2006 setzt sich aus verschiedenen Vektordaten und Satellitendaten zusammen:

- **Digitales Landbedeckungsmodell DLM-DE2009:** Das DLM-DE 2009 beruht auf dem ATKIS Basis-DLM zum Jahr 2009, erstellt in Verantwortung des BKG, überprüft und aktualisiert mit diversen hochauflösenden Satellitendaten von RapidEye und DMC. Es bildete die Ausgangssituation für das „Backdating“ zurück auf das Jahr 2006.
- **ATKIS Basis-DLM Flacher Layer 2006 Bundesländer:** In Form eines aufbereiteten und überlappungsfreien Vektordatensatzes, aber ohne eine Überprüfung und Aktualisierung durch Satellitendaten, stand das ATKIS Basis-DLM 2006 für alle Bundesländer zur Verfügung, eingefroren zum Stand des Frühjahrs / Frühsommers 2006.
- **CORINE Land Cover 2006 (mit 25 ha MKF):** Wegen der Mindestkartierfläche von 25 ha wurden die Daten von CLC2006 nur für spezielle Situationen in direkter Form eingesetzt, dienten aber in größerem Umfang auch zu Vergleichszwecken..
- **Satellitendaten IMAGE2006 Frühjahr und Sommer:** Noch vom herkömmlichen EU-Projekt der Erstellung von CORINE Land Cover 2006 stand die Satellitendatenbasis IMAGE2006 mit Satellitendaten von IRS-P6 LISS-III sowie von SPOT-4 HRVIR und Spot-5 HRG zur Verfügung, mit einer Frühjahrsüberdeckung und einer Sommerüberdeckung.
- **Satellitendaten Landsat-5 Sommer:** Eine Deutschland weite Landsat-Überdeckung bildete eine zusätzliche homogenere Sommer-Überdeckung für 2006, gleichzeitig ein Backup für kritische Regionen mit Einschränkungen hinsichtlich der atmosphärischen Bedingungen bei IMAGE2006.
- **Satellitendaten AWiFS 2005 / 2006 multisaisonal:** In Vorstudien hatte sich das hohe Potential von multi-saisonalen AWiFS-Daten zur Unterscheidung von Ackerland und Grünland gezeigt. Die

AWiFS Daten mit räumlicher Auflösung von ca. 60 m wurden für die Ableitung von Indikatoren zur Kennzeichnung der Vegetationsdynamik eingesetzt, die diese Unterscheidung stark unterstützt. Die 43 AWiFS Szenen für die multi-saisonalen Überdeckungen Deutschlands wurden mit Projektmitteln beschafft.

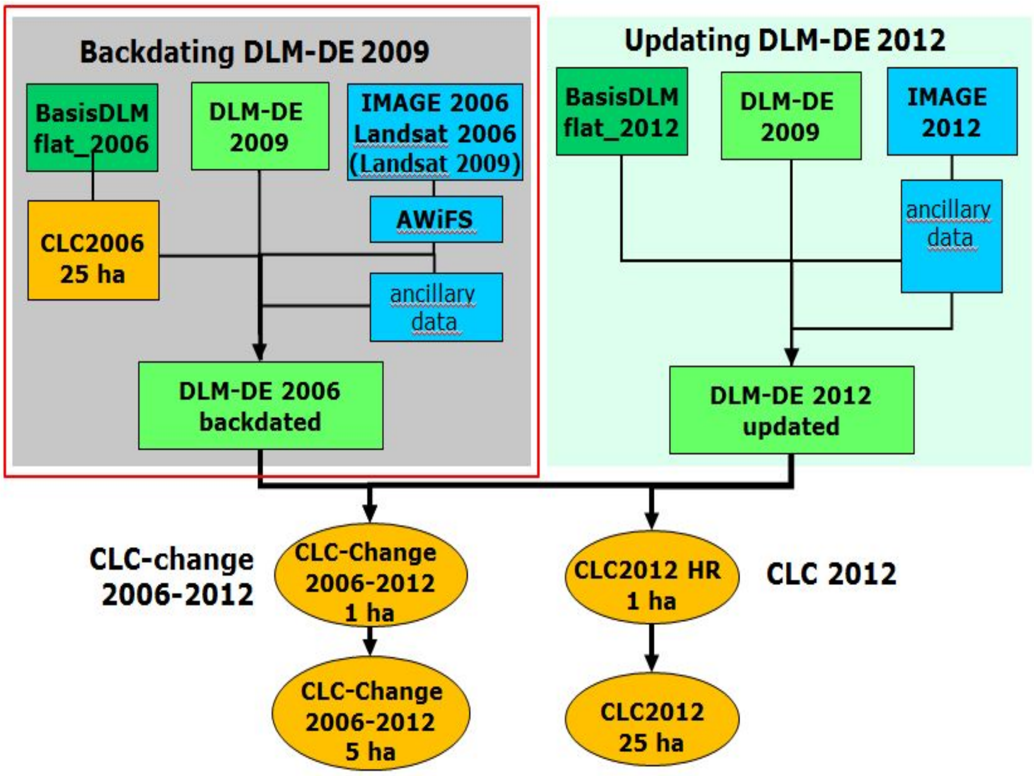
- **Soil Sealing Layer 2006:** Der vom UBA zur Verfügung gestellte Informationslayer, der in zwei Varianten vorliegt, zeigt für die Mitgliedsstaaten der EEA die bebauten Flächen mit ihrem Grad der Versiegelung zwischen 1% und 100%, abgeleitet aus der IMAGE2006 Datenbasis. Die primäre Version „EEA Fast Track Service Precursor – Degree of soil sealing" umfasst neben bebauten Flächen auch Abbaugebiete und noch offene Baustellen. Die Version „Revised Soil Sealing 2006, degrees of sealing 20 m and 100 m" wurde im FP7-Projekt Geoland2 komplett überarbeitet und enthält nicht mehr die Flächen von Abbaugebieten.
- **Regional vorhandene Daten:** Hier standen in verschiedenen Regionen Deutschlands Produkte zur Waldkartierung aus dem Projekt „GSE Forest Monitoring" zur Verfügung, unter der Federführung der GAF AG erstellt.

Figure 4: Klassifizierungsschema der Bodenbedeckungsklassen gemäß CORINE Land Cover in Deutschland und ihre Farbzuordnung.



Eine Zusammenfassung der Datenströme und Verarbeitungsschritte (als Teil des Gesamtprojektes CLC2012) ist in Figure 5 dargestellt. Sichtbar werden die zwei Aufgaben: Zum einen die Aufgabe des Updating zur Beschreibung des CLC-Status im Jahr 2012, zum anderen die des Backdating als Teilaufgabe zur Ableitung der Änderungen „CLC-Change" zwischen 2006 und 2012. Das Updating (rechter Datenstrom) wurde wie eingangs erläutert durch das BKG durchgeführt.

Figure 5: Die zwei Teilaufgaben des Updating und Backdating bei der Erzeugung von CLC2012 und CLC-change (2006 – 2012) und die zugehörigen Datenströme. Quelle: BKG Präsentation auf dem Kickoff Meeting „CLC Backdating" am 27.9.2012, verändert.



2.3 Methodik

Als Softwaretools wurden im Projekt fünf verschiedene Systeme verwendet. Das Prozessierungssystem CATENA des DLR-Instituts für Methoden der Fernerkundung wurde für verschiedene Schritte der Vorverarbeitung eingesetzt. Für die GIS-bezogenen Arbeiten wurde die GIS-Software ESRI ArcGIS 10 verwendet. Für die Bildverarbeitung kamen ERDAS Imagine Version 2001 und (insbesondere für die Bildsegmentierung) eCognition Developer Version 64 der Firma Trimble zum Einsatz, daneben die „Interactive Description Language" IDL (Version 7.1 bzw. 8.1).

Ansatz der Ermittlung hauptsächlicher Änderungsprozesse:

Für die Rückdatierung des DLM-DE2009 auf die Situation der Landbedeckung in 2006 wurde ein Ansatz gewählt, der von den häufigsten 46 Änderungsklassen (basierend auf den Änderungen zwischen 2000 und 2006, ermittelt bei CLC2006) ausging. So machten die ersten acht Veränderungsprozesse mit Veränderungen der Waldzusammensetzung durch Sturmwurf und Nutzung sowie Waldaufwuchs, Übergang von Grünland zu Ackerland in der Landwirtschaft und Entstehung neuer Wohnbebauungen, Industrie- und Gewerbeflächen und Abbaugebieten auf Ackerflächen bereits 51,2% der kumulierten anteiligen Änderungsfläche aus (siehe Table 2). Bei der Berücksichtigung der 46 häufigsten Änderungsklassen resultierte bei CLC2006 eine Abdeckung von 89,7 % der gesamten Änderungsflächen. Mit entsprechender Gruppierung der Änderungsklassen sollte möglichst weitgehend auf zu generierende thematische Rasterlayer zum Referenzjahr 2006 (z. B. Layer der Abbauflächen CLC Klasse 131 in 2006) zurückgegriffen werden, um deren jeweilige Anteile in den Polygonen des DLM-DE2009 als Indikator für Änderungen zu bestimmen. Mittels Segmentierung der generell von Änderungen betroffenen Polygonen, beruhend auf hochaufgelösten Satellitendaten z. B. von IMAGE2006, sollten dann auch Teilflächen in den Änderungspolygonen mit einbezogen werden.

Vorverarbeitungsschritte:

Als Arbeitseinheiten wurde Deutschland in sechs Makroregionen eingeteilt, die auf einzelnen oder Gruppierungen von Bundesländern beruhten. So enthielt Makroregion BY die Fläche von Bayern, NW die Fläche von Nordrhein-Westfalen, Hessen, Rheinland-Pfalz und Saarland. Als Grundlage für die spätere Segmentierung wurden Mosaike der IMAGE2006 Überdeckungen im Frühjahr und im Sommer, jeweils für die Makroregionen, erstellt, als Zusatzdatensatz zudem ein jeweiliges Mosaik von Landsat-Daten aus dem Sommer 2006. Eingebungen waren entsprechende Ableitungen von Wolken- und Wolkenschattenmasken zur Definition ungültiger Mosaik-Bereiche. Da die IMAGE2006 und Landsat Mosaike nur für die Abgrenzung von Objekten im Segmentierungsschritt verwendet werden sollten, konnte auf eine radiometrische Anpassung der Einzelszenen verzichtet werden.

Table 2: Die dominierenden 8 Veränderungsklassen gemäß den „CLC_Changes“ zwischen 2000 und 2006 in Deutschland

Legende:
Intensivierung in der Landwirtschaft
Extensivierung in der Landwirtschaft
Aufforstung
Flächen mit Waldverlust
Urbanisierung/ Zunahme der Versiegelung
Neue Abbaufläche
Rekultivierung von Abbauflächen
Neue Wasserfläche
Sonstige Änderung

Rang Nr.	Übergang	Deutschland		
		Fläche [km²]	Anteil	Kumuliert
1	312 → 324	265,30	11,77%	11,77%
2	231 → 211	192,87	8,56%	20,33%
3	211 → 112	178,61	7,92%	28,25%
4	324 → 313	157,95	7,01%	35,26%
5	324 → 312	117,93	5,23%	40,49%
6	211 → 131	86,09	3,82%	44,31%
7	133 → 112	77,81	3,45%	47,76%
8	211 → 121	77,21	3,43%	51,18%

Als eine der thematischen Informationsebenen sollte für den Bereich der landwirtschaftlichen Flächen (Entscheidung, ob Acker- oder Grünlandflächen in 2006) multi-saisonale Information aus den IRS-P6 AWiFS mit integriert werden. Dies machte die Ko-Registrierung der AWiFS-Daten, den Aufbau von multi-saisonalen Mosaiken von AWiFS zum Beispiel für die Monate April, Mai, Juli und September und die Ableitung temporaler Statistiken für AWiFS notwendig. Als Indikator, der die Vegetationsentwicklung einzelner Objekte (die phänologische Entwicklung) über das Jahr beschreibt, wurde jeweils der Vegetationsindex NDVI („Normalized Difference Vegetation Index“) abgeleitet. Die Dynamik des temporären NDVI-Verlaufs bei landwirtschaftlichen Flächen enthält wertvolle Informationen bezüglich der wahrscheinlichen Zugehörigkeit zu Ackerland oder zu Grünland, z. B. bei Nutzung der Parameter Minimum, Maximum, Mittelwert und Standardabweichung.

Ableitung thematischer Rasterlayer:

Die ermittelten thematischen Rasterlayer zum Status von 2006 hatten zum Teil den Stellenwert von Interimslayer, die dann mit verschiedenen logischen Verknüpfungen weiter verarbeitet wurden. Zum anderen Teil waren es Rasterlayer, wie z. B. ein abgeleiteter Layer der Abbaugebiete (CLC-Klasse 131) zum Stand 2006, die direkt für die Erfassung möglicher Übergänge der Landbedeckung eingesetzt werden konnten (z. B. beim Übergang von 131-> 512, Abbaugebiet in 2006 zu Wasserfläche in 2009).

Als Interimslayer sind zu nennen:

- Zwei Varianten des *Layers zur Bodenversiegelung 2006* (dem „Soil Sealing Layer 2006", einmal inklusive, einmal exklusive Abbauflächen und Baustellen, Informationsebene für Abbauflächen in 2006),
- *Bebauungslayer 2006* aus dem Basis-DLM_2006_flach (mit hohem Aktualitätsgrad), mit mindestens einer der CLC-Kategorien 111, 112, 121,
- *Layer zur Waldbedeckung 2006* aus dem Basis-DLM_2006_flach (ebenfalls mit hohem Aktualitätsgrad bezüglich der Waldaußengrenzen), mit mindestens einer der Waldkategorien in CLC von 311,312,313,324.

Aus Kombinationen mit den Interimslayern und Satellitendatenprodukten, oder allein aus der Satellitengrundlage, wurden folgende Rasterlayer abgeleitet, die direkt als Landbedeckungssituation in 2006 eingebracht werden konnten:

- *Wassermaske* (CLC 512), ermittelt durch kombinierte Schwellwertklassifizierungen aus drei abgeleiteten Indizes der Landsat-Mosaike (NDVI, Wasserindex MNDWI laut Xu, SWIR-Kanal); bei den abzuprüfenden Beiträgen potentieller Änderungsflächen spielt die Klasse keine Rolle, wohl aber bei Gegenchecks z. B. bezüglich Abbaugebieten in 2006,
- *Abbaugebiete* (CLC 131), ermittelt durch ein komplexes Regelwerk unter Nutzung der zwei Varianten der Bodenversiegelung, der Datenbasis DLM-DE2009 (mögliche Folgeklassen), CLC2006 und den einzelnen Landsat-Daten 2006,
- *Baustellen* (CLC133), Nutzung der zwei Varianten der Bodenversiegelung, mit Zusatzregel der Zugehörigkeit zu einer der CLC-Klassen 133, 111,112,121,122 in DLM-DE2009,
- *Ackerflächen* (CLC 211), Abgrenzung durch Kombination von Schwellenwerten der temporalen Statistik der NDVI-Zeitreihen von AWiFS Satellitendaten, Ausklammerung von bebauten Flächen, Waldflächen, Wasserflächen in 2006,
- *Grünlandflächen* (CLC 231, ev. CLC 321), ebenfalls Abgrenzung durch Kombination von Schwellenwerten der temporalen Statistik der NDVI-Zeitreihen von AWiFS Satellitendaten, Ausklammerung von bebauten Flächen, Waldflächen, Wasserflächen in 2006, z. T. weiterer Flächen,
- *Waldverteilung bezüglich der Waldklassen* (CLC 311, 312, 313, 324), Diversifizierung innerhalb der Waldmaske 2006, Nutzung von CLC2006, Berechnung der Feinverteilung der Waldflächen mit Status 324 in DLM-DE2009 bezüglich (noch) 312 in 2006 oder (schon) 324 in 2006 aus IMAGE2006 bzw. Landsat, insbesondere mittels des SWIR-Kanals,
- *Nur regional verbreitete Landbedeckungen* (CLC 222, 321, 331, 333), mit der Ausgangssituation bestimmt durch CLC2006, teilweise bearbeitet durch manuelle Verfeinerungen.

Integration der Informationen aus DLM-DE2009, Satellitendaten 2006 und Rasterlayer 2006:

Durch die Erzeugung der 12 thematischen Rasterlayer, die die thematische Information zum Jahr 2006 tragen und jeweils einer CLC-Klasse entsprechen (siehe vorheriges Kapitel), wurden die Teilnehmer-Klassen in 2006 an den hauptsächlichen Änderungen und deren räumliche Verteilung in 2006 festgelegt. Zur Modellierung des Backdating-Datensatzes waren dazu folgende weitere Aufgaben durchzuführen:

- Ermittlung der potentiell von Änderungen betroffenen Polygone im Gerüst der Geometrie des DLM-DE2009 Datensatzes (Berechnung zonaler Statistiken),
- Feststellung, welche Polygone gänzlich (bzw. in entsprechender Dominanz) einen Übergang zu einer anderen CLC-Klasse in 2006 anzeigen (Auswertung der zonalen Statistiken),
- Unterteilung der Polygone, die in Teilbereichen von Änderungen zwischen 2006 und 2009 betroffen sind, mit Hilfe von Segmentierungsverfahren und unter Nutzung geeigneter hochauflösender Satellitendaten – dabei Nutzung der drei Mosaike „Sommeraspekt LISS-III" mit Wolkenmasken, „Frühjahrsaspekt LISS-III" mit Wolkenmasken, „Sommeraspekt Landsat-5 Thematic Mapper" mit Wolkenmasken;
- Zuordnung der jeweiligen dominanten CLC-Klasse laut der thematischen Rasterlayer zu den ermittelten Untersegmenten (Auswertung der zonalen Statistiken) und Ausgabe der Änderungspolygone.

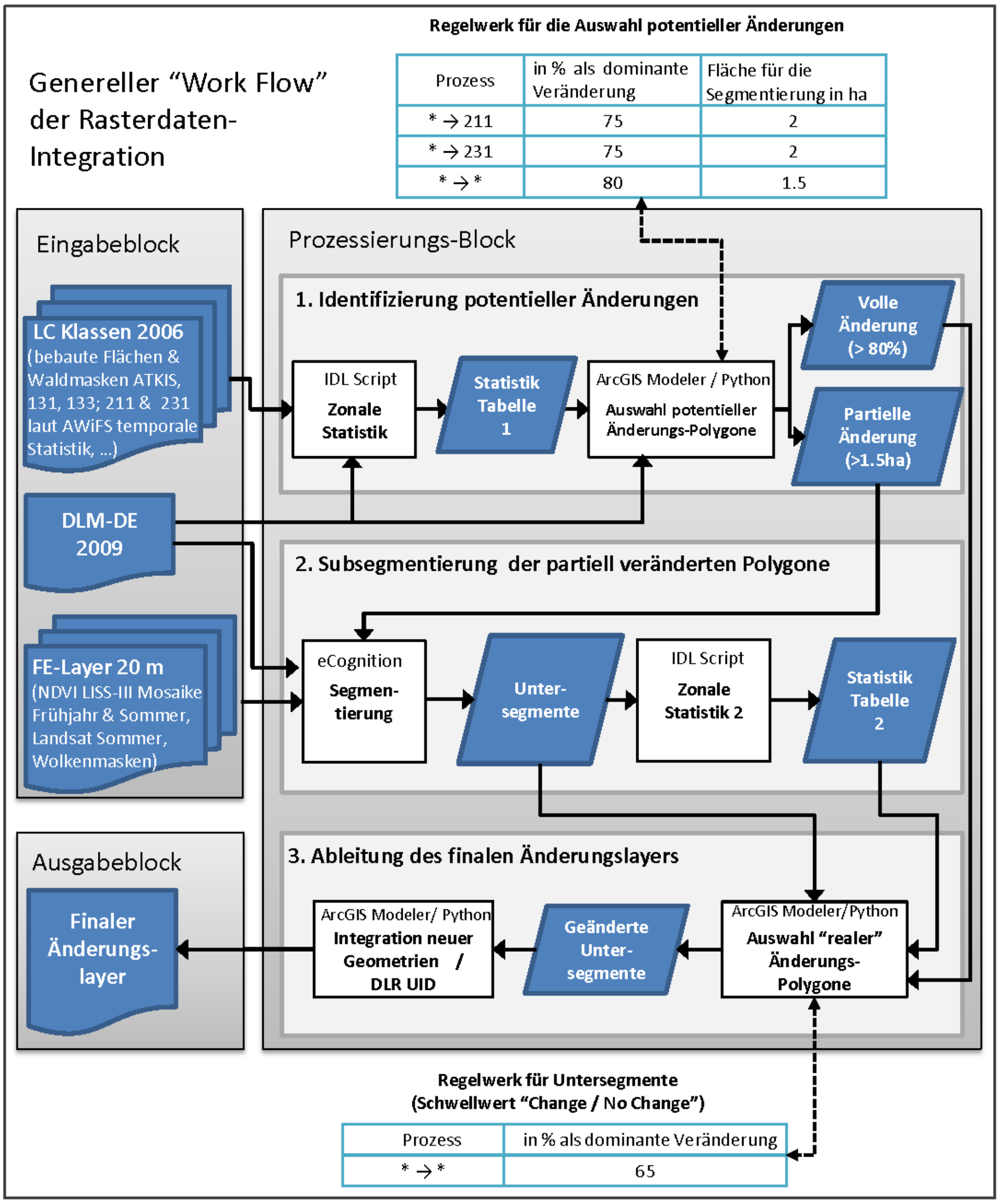
Der Arbeitsablauf mit dem entsprechenden Datenfluss ist als Übersichtsgraphik in Figure 6 dargestellt.

Plausibilitätschecks und Verbesserung der Änderungspolygone:

Bei den ermittelten Änderungspolygonen gegenüber dem Stand in 2009 wurden eine Reihe von Plausibilitätschecks durchgeführt und die Ergebnisse zunächst in einem Zusatzattribut festgehalten. Am Anfang standen dabei Überprüfungen hinsichtlich der Polygongröße unter 0,5 ha bzw. 1 ha und hinsichtlich von Formparametern, die schmale Objekte identifizieren sollten. Die so charakterisierten Polygone wurden nicht mit in die Plausibilitätsprüfungen einbezogen, aber standen später im Zusammenhang mit komplexen Änderungen mit zur Verfügung.

Als ein Beispiel seien notwendige Checks auf potentielle Änderungen von Ackerland oder Grünland (CLC-Klasse 211 oder 231) zur CLC-Klasse 142, Sport- und Freizeitanlagen, genannt. Diese Klasse ist weder in der Bebauungsmaske noch in der Waldmaske integriert und wird so in die Klassifizierung bezüglich Ackerland oder Grünland in 2006 mit einbezogen. Die meisten solcher angezeigter Änderungen sind nicht echt, aber eine Prüfung ist notwendig, um echte Änderungen von Ackerland oder Grünland zu neuen Golfplätzen zu identifizieren.

Figure 6: Verarbeitungsablauf bei der Integration von Satellitenbilddaten, thematischen Rasterebenen und den Inputdaten der DLM-DE 2009 Vektordatenbasis.



Bei einer Reihe von ermittelten Änderungskategorien, die im Zuge des automatischen Verarbeitungsansatzes entstehen, werden häufig keine echten Änderungen dargestellt. Eine Überprüfung und entsprechende Aktion ist aber, wie die Praxis gezeigt hat, notwendig. Ein Beispiel sind Sport- und Freizeitflächen, die meist in keiner der Masken wie Bebauungsmaske oder Waldmaske von 2006 enthalten sind, bei der Schwellwertklassifizierung von Ackerland und Grünland mit erfasst werden und dann fälschlich einer Änderungsfläche zugeordnet werden. Um den Änderungsprozess der Neubildung von Golfplätzen auf landwirtschaftlichen Flächen zu erfassen, ist aber ein Check dieser Flächen mittels Zoom und eventuell Zusatzinformation aus Webdiensten notwendig.

2.4 Ergebnisprodukte

Die Ergebnisprodukte wurden sukzessive für die einzelnen Makroregionen oder auch Untereinheiten der Makroregionen an das BKG zur weiteren Datenintegration ausgeliefert. Dabei wurden sowohl die überarbeiteten Änderungslayer (ab 1 ha Änderungsfläche) als auch die auf das Jahr 2006 rückdatierte Gesamtsituation der Landbedeckung im Datensatz CLC2006_Backdating (1 ha MKF) erzeugt.

2.5 Datenqualitätsbetrachtungen

Es zeigte sich, dass bei den angezeigten Änderungsflächen in der Landwirtschaft mit der Zuordnung der Acker- und Grünlandflächen in 2006 ganzflächige Überprüfungen notwendig waren, allerdings aus Zeitgründen mit einem Überprüfungsmaßstab von 1:30000 bis 1:40000. Für die Gesamtentscheidung, ob als echte oder keine Änderung markiert wurde, gingen neben der temporalen AWiFS Entscheidung auch die visuelle Inspektion der drei hochaufgelösten Satellitenbildmosaike ein. Es zeigte sich, dass die AWiFS Indikatoren z. B. in Flussauenbereichen häufig durch temporale Hochwasserstände gestört waren und dann falsche Änderungen anzeigten.

Auch waren die abgeleiteten Statistik-Parameter Minimum, Mittelwert und Standardabweichung von der Repräsentativität der vorhandenen Zeitabschnitte in den AWiFS-Aufnahmen und von der lokalen lückenfreien oder lückenhaften Überdeckung durch 4 bis 7 Szenen abhängig. In der Gesamtheit der Nutzung von AWiFS Indikatoren und den drei Mosaik-Varianten von LISS-III bzw. Landsat war eine wesentliche Verbesserung der Zuordnung zu echten bzw. nicht echten Änderungen bei den landwirtschaftlichen Flächen möglich. Es ist anzunehmen, dass durch eine Verbesserung bei der saisonalen Überdeckung, z. B. durch Zeitreihen der zukünftigen Sentinel-2 Daten, auch die automatisch abgeleitete Ackerland-Grünland-Trennung noch optimiert werden kann.

Eine flächige Überprüfung angezeigter Änderungspolygone wurde auch im Zusammenhang mit Änderungen auf den Waldflächen durchgeführt, sowie bei Prozessen im Umfeld von größeren Abbaugebieten. Bei anderen Änderungstypen wurden zunächst jeweils die pro Änderungskombination flächenmäßig größten Polygone überprüft und die Checks dann auf kleinere Polygone ausgedehnt. Teilweise wurde dies kombiniert mit flächigen Überprüfungen in Regionen mit Anzeichen von Fehlzuordnungen bzw. in „Hot Spots“ von Änderungen.

2.6 Fazit

Die angewandte Methodik einer semi-automatischen Erfassung von Änderungen, ausgehend von den 46 Änderungsklassen, für die eine Abdeckung von etwa 90% der Änderungsflächen erwartet werden kann, hat sich als eine praktikable Methodik mit zufriedenstellenden Ergebnissen erwiesen. Allerdings war zunächst eine recht umfangreiche Vorverarbeitung insbesondere bei der Erstellung der verschiedenen Satellitenbildmosaiken notwendig, und auch die Überprüfung und Verbesserung der automatisch ermittelten Änderungspolygone nahm einen größeren Umfang an wie anfangs abgeschätzt. Angesichts der großen Datenmengen bei DLM-DE mit 1 ha MKF ist zu erwähnen, dass eine effektive Vorauswahl der potentiellen Änderungspolygone und eine handhabbare Segmentierung begrenzt auf nur diese Ausgangspolygone ein entscheidender Schritt im Projektverlauf war.

Bei einer zu erwartenden besseren multi-saisonalen Datengrundlage in der zukünftigen Sentinel-2-Ära kann auf eine verbesserte multi-saisonale Abdeckung für Analysen im Bereich der landwirtschaftlichen Flächen gehofft werden, so dass ähnliche semi-automatische Vorgehensweisen auch im Zusammenhang mit der vorausschauenden Aktualisierung von Datenbasen der Landbedeckung unter Nutzung bestehender Vektorgeometrien denkbar sind.

3 Introduction

3.1 Initial Situation

The Federal Environment Agency (UBA) is the national responsible institution for the update of CORINE Land Cover (CLC) in Germany since the primary assessment for the year 1990, in the frame of the European wide CLC program coordinated by the European Environment Agency. Since 2012, UBA shares this responsibility with the German Federal Agency for Cartography and Geodesy (BKG). On behalf of the Federal Environment Agency, the German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR) performed the updates CLC2000 and CLC2006 (Keil et al., 2005; Keil et al, 2010 a).

Due to a change of the applied methods, the further update of CORINE Land Cover in Germany, CLC2012, is done under the responsibility of BKG. The approach is based on the more accurate geometry and the thematic attributes of the Official Topographical Cartographic Information System ATKIS of the land survey authorities. The update of the land cover situation is, besides the use of most recent ATKIS version, also based on the satellite data of the reference year 2012. The assessment of land cover by this approach, motivated by national needs, was for a first time performed for the year 2009. The final product was the "Digital Landscape Model for Germany" DLM-DE 2009, built-up with a minimal mapping unit (MMU) of 1 ha. The recent database of DLM-DE 2012 is at this time under production under the responsibility of BKG and will be transferred via generalization methods into the database CLC2012 (with 25 ha MMU due to the EU specifications).

DLR-DFD was engaged in CLC2012 only in a part of database creation, in which the objective was the deduction of "CLC_Change" between 2006 and 2012 – the second product for the status 2012 besides the updated database in 2012. Due to the change of method in relation to the conventional CLC approach, the use of a special approach became necessary for this task which can be named a retrospective view or a "backdating" of DLM-DE 2009 to the situation of land cover in 2006, in the geometry of DLM-DE.

In the following, the **historical development** will be described which lead to the specific project approach of CLC2006_Backdating as a step for the deduction of the change dataset CLC_Change.

Already during the User Workshop 2004 in Berlin, during the finalization of **CORINE Land Cover 2000**, the needs of German and other European users for a spatial and partly also thematic higher resolved dataset CORINE Land Cover became evident (Mohaupt & Keil, 2004; UBA, 2004). Also Europe-wide the increasing and more detailed information needs concerning land use were taken up in the frame of the **Copernicus Program** (formerly **GMES,** „Global Monitoring for Environment and Security"). Since 2001, various geo-service developments were initiated in EU and ESA programs in the field of land monitoring (GSE Forest Monitoring, 2010, BOSS4GMES, 2011, Geoland2, 2010, Geoland2, 2012, Copernicus EU, 2013, D-Copernicus, 2013, Copernicus, 2014, Kuntz et al., 2014). Partly, these service developments had also the goal to supplement the information layers of CLC.

Within these programs, a dataset of sealed areas was produced reflecting the status of 2006 (performed in the frame of the „Fast Track Service Precursor Land", FTS-Land). This product includes also the degree of soil sealing between 1% and 100%. The dataset „FTSP Soil Sealing 2006"was created using the satellite data base of „IMAGE2006". It covers all member states of the European Environment Agency, has a primary pixel space of 20 m by 20 m, with an additional aggregation of 100 m by 100 m, and was updated in the frame of the subsequent Copernicus project „Geoland2" for the reference year 2009 (EEA, 2010; Gangkofner et al., 2010).

Other geo-service developments, integrated in the Geoland2 sub-project EUROLAND, aimed to introduce 5 thematic **„High Resolution Layers" (HRL)** for a more detailed characterization of land use and land cover.

- Besides the assessment and the characterization of sealed areas as one of these layers ("HRL Soil Sealing" or "Impervious Layer"), the following four "HRL Layers" were included:
- A forest layer, the "HRL Forest", with a forest mask (with a crown cover of 10% upwards), associated with information on the crown cover density and the shares of deciduous and coniferous trees, derived by regression methods from satellite imageries,
- a grassland layer ("HRL Grassland"),
- a wetland layer ("HRL Wetlands"),
- and a layer of permanent water bodies ("HRL Water").

The mentioned "High Resolution Layers" were derived in various demonstration areas or along border crossing transects in Europe, based on the satellite database of „IMAGE2009" (GMES-GEOLAND, 2010a, GMES-GEOLAND, 2010b) and supplemented by multi-temporal data of the IRS-P6 AWiFS Sensor. Building on these geo-service developments, EEA initiated the project GIO Land („GMES Initial Operations") during summer / autumn 2011, with the objective to cover 39 states in Europe by the corresponding „Pan-European High Resolution Layers" (EEA, 2012) – now part of the „Copernicus Land Monitoring Services" (Copernicus Programme, 2014). Multi-seasonal and also multi-sensoral data play a bigger role especially for the layers „HRL-Forest", „HRL-Grassland", „HRL-Wetlands", and „HRL-Water". Some experiences during the creation of the European Grassland Layer are reported by Zillmann et al (2014).

In the national (German) context, the geo-service developments were supported by the joint project DeCover, thought as a national interface project to the European activities within COPERNICUS / GMES. In **DeCOVER,** methods for updates and extensions of land cover information were developed. In addition, adapted approaches for the information needs of national and regional competent authorities were elaborated (e.g. in the fields of agriculture and nature protection; DeCOVER 2, 2012, EFTAS, 2012).

During the last years, efforts were undertaken by a number of EU member states to integrate also national viewpoints in new land use and land cover updates, and to build on national available geo-databases, but also on available programs and datasets of the EU member states. For the insertion into the European wide datasets, this approach requires a subsequent adaptation onto the requirements on the European level, e.g. concerning the minimum mapping units. This approach in European programs on land cover updates is called **„bottom-up approach"**. It was persecuted already for CLC2006 by Spain (Arozarena et al., 2006).

Also in Germany, a correspondent discussion process took place along several years, to integrate existing databases into the update process. It was obvious to use the Official Topographical Cartographic Information System ATKIS for the initial base (AdV, 2012; AdV, 2013). ATKIS has been built-up and updated by the land survey authorities of the federal states. Responsible for the coordination of the complete database for Germany is the German Federal Agency for Cartography and Geodesy (BKG).

During the update of land cover in Germany for **CORINE Land Cover 2006** (Keil et al., 2010 a), it was already a special aspect within a cooperation between UBA, BKG and DLR, to investigate in which form and by which additional efforts the database of ATKIS can be included in the update process (Keil et al, 2010c). A special focus was to convert the database onto the higher geometric accuracy of ATKIS and into a dataset derived from ATKIS, the "Digital Landscape Model of Germany" (DLM-DE) (Keil et al, 2010c). DLM-DE, now officially called the "Digital Land Cover Model of Germany", lies in the responsibility of BKG (BKG 2012). It has been prepared for covering needs of various resorts and authorities on the national and federal state level (Arnold, 2009 a, b). Aspects of an associated study were tests of more automated classification approaches, an approach for the deduction of changes during the method modification, and possible approaches of an adequate later generalization to the 25 ha MMU of the CLC dataset (Keil et al, 2010c; see also Keil et al, 2010b; Metz, 2009; Metz et al., 2009; Nieland, 2009; Nieland et al., 2009).

During the years 2007 / 2008, an approach was developed at DFD during a **feasibility study on behalf of BKG** to build on the geometry of ATKIS Basis-DLM, but also to build as far as possible on the attributes of area based ATKIS objects. One main objective was to derive a high resolution database of CORINE Land Cover to the status of 2006 in several test regions. Satellite data of IMAGE2006 in a combination of spring and summer coverages were used for the update (Bock et al. 2008). It was demonstrated that partly direct transformations from the ATKIS attributes into the CLC code were possible. In other parts, a specific code had to be derived out of the context of the specific land cover situation in the satellite images. Depending on the local state of update status in ATKIS and the acquisition date of the former used air-photos, also updates based on the new satellite images were necessary. Arnold (2009a) discusses in detail the data model of DLM-DE with the integration of basic geo-data and geo-data from satellite imagery during the update process.

In a next step, an updated version of the database DLM-DE had been created in the responsibility of BKG for the year 2009. The update for **DLM-DE 2009** was mainly performed using RapidEye satellite data in a spatial resolution better than 10 m. A consortium of companies on behalf of BKG used the ATKIS Basis-DLM database available in mid of 2009 as primary basis. Instead of the single layers of the Basis-DLM with aerial ATKIS object types allowing overlapping geometries, BKG made available a deduced so-called flat layer "Basis-DLM_flat". This layer contains the CLC relevant land cover and land use classes without overlapping regions, supplemented by an additional layer containing the overlapping areas and objects (Arnold, 2009b). Missing CLC classes not provided in the Basis-DLM were integrated during the update process. On the national level, the minimum mapping unit (MMU) of DLM-DE 2009 is 1 ha (for water bodies ½ ha).

The database DLM-DE 2009 provides the basis of the new update in **DLM-DE 2012**, which is under production this time under the leadership of BKG (in a national project). DLM-DE 2012 with MMU of 1 ha will lead to the **German contribution of CLC 2012** (MMU 25 ha) for EEA, by a subsequent generalization. The information of too small units within the generalization will be respected in the constructed thematic neighborhood relations and polygons.

As a second dataset for CORINE Land Cover 2012, the change layer is needed, which contains the polygons with changes from 5 ha upwards between the 2006 assessment and the status of 2012 (**CLC_Change**). As an interim status, the product DLM_DE2009 of BKG is available. The changes from the status of DLM-DE 2009 to 2012 will be directly mapped by the BKG team during the update process. The agreed part of UBA and DLR-DFD was to contribute the main change areas between 2006 and 2009 during the phase of method change. This should be done by semi-automated methods on the base of 1 ha geometries in order to model the status of land cover at 2006 in a finer geometry and thus to produce a comparable initial basis for the change layer in relation to 2012.

3.2 Objective

The primary objective during the backdating project is to produce an interim dataset „CLC2006_Backdating“ by a minimum mapping unit (MMU) of 1 ha which will later give (together with DLM-DE 2012) the starting base for the deduction of CLC_Change between 2006 and 2012. Afterwards, this dataset has to be generalized at BKG for the European planning level to grant a minimum mapping unit of 5 ha.

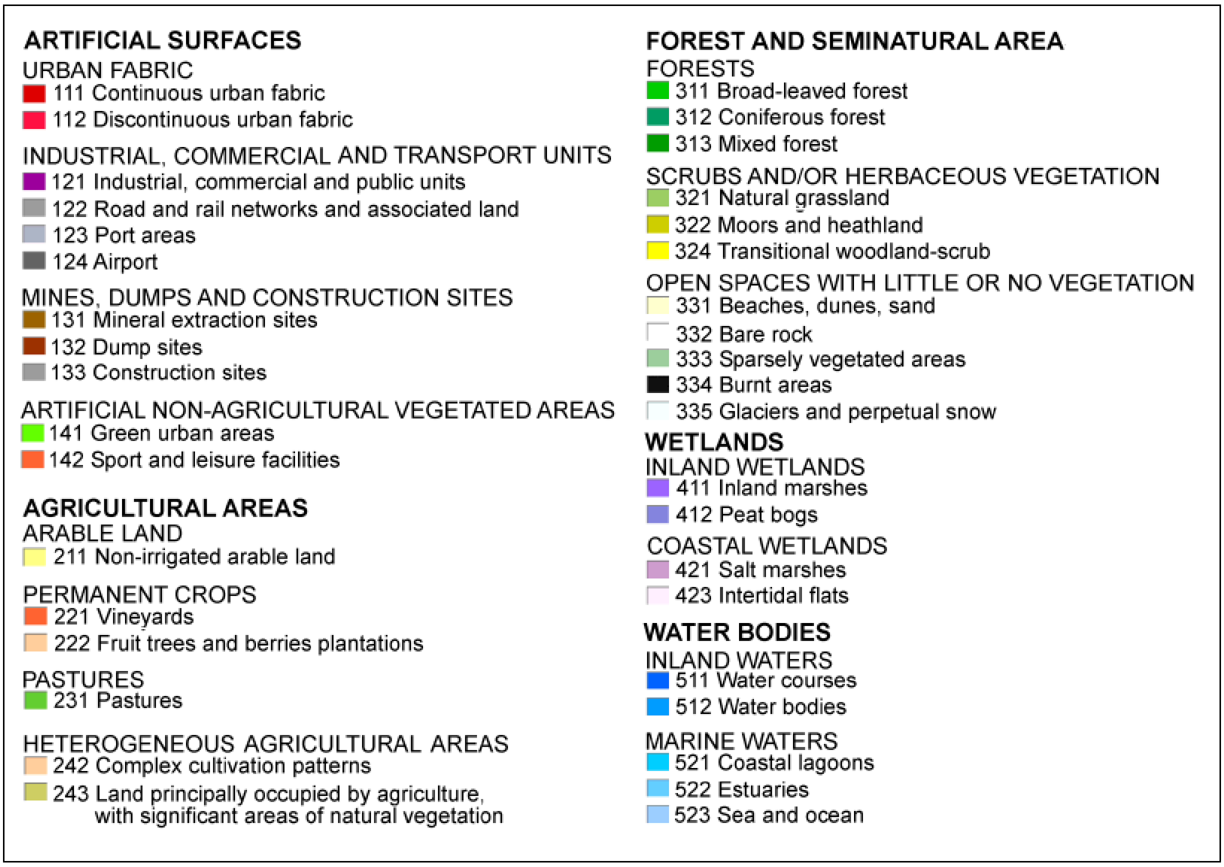
In the following, the objectives for the project “Updating the CLC land use and land cover data for 2012 – „Backdating” the DLM-DE from the reference year 2009 back to 2006” will be summarized:

By using the Basis-DLM and the deduction of DLM-DE 2009 database with updated CLC classes, the units of land cover and land use due to the CLC nomenclature are transferred into the geometry of the Official Topographical Cartographic Information System ATKIS (for the definition of CLC classes in Germany see Figure 7). The change of methodology for the CLC update to the reference year 2012 in relation to 2006 (with DLM-DE 2009 as basis for the update) opens new national and regional opportunities of utilization. By the subsequent generalization of CLC polygons of 1 ha MMU to 25 ha MMU, an adequate dataset can be derived for the use at the European Environment Agency EEA and for further user groups in the national and international environment.

In the European and national context, the change layer between 2006 and 2012 (CLC_Change) is needed besides the recent product CLC2012, providing information on the development of land cover categories, with a defined minimum mapping unit of 5 ha. An update of DLM-DE 2009 for the year 2012 allows a direct assessment of changes for this period of three years, being in the responsibility of BKG. But the requested total changes are composed of a combination of change processes from 2006 to 2009 and from 2009 to 2012. For the consideration of both components in the change layer, a putting on the more detailed geometry of DLM-DE 2009 is reasonable, which was a main result in a parallel study to the CLC2006 assessment in Germany (Keil et al., 2010 c). Otherwise, local deviations and real temporal changes would be mixed as consequence of the change of method and the different geometries connected with the delineation of objects (in the direct comparison with CLC2006 database).

Thus, the task remains to derive the status of land cover / land use in 2006 as effective as possible in the geometry of DLM-DE. For this task, the main change processes are to be regarded, and if possible, automatic or semi-automatic methods are to be applied. In view of the anticipated large number of change processes within agricultural areas, the potential of multi-seasonal satellite data by AWiFS time series around 2005 / 2006 was to be used. By these multi-seasonal datasets, the different phenological development of arable land and grassland can be assessed and be used as an indicator for separation. Further on, high-resolution geo-information products like the two available variants of soil sealing layer („Soil Sealing 2006“) are to be integrated in the evaluations. These information layers were produced already in the context of GMES / Copernicus programs. Further high-resolution thematic raster layers to the status of 2006 are also to be derived as interim products.

Figure 7: Scheme of land cover classes due to CORINE Land Cover in Germany, including color coding.



4 Data basis

4.1 Input data

4.1.1 ATKIS Basis-DLM Flat Layer 2006 Federal States

As most important input layer for the backdating of the Digital Landscape Model DLM-DE 2009 to 2006, BKG made available at the project start the ATKIS data base, in the form of ATKIS Basis DLM, with separate datasets for each of the 16 federal states. The delivery status in the various ATKIS datasets was spring / early summer 2006. Due to BKG, it can be assumed that built-up areas and traffic infrastructure had a high timeliness at this delivery date. Concerning other land cover & land use types, e.g. the type of use for agricultural areas (arable or grassland), the dates of assessment can be several years before the delivery date, dependent especially on the dates of air-photo recording. For the ATKIS Basis DLM for 2006, no update by satellite imagery was available.

The ATKIS Basis DLM is composed by the aerial based object types (in the old ATKIS model), which are based on 99 selected object types from the sections settlements, traffic infrastructure, vegetation and water bodies, being relevant for the modelling of land cover and land use information. The objects are grouped in 17 ATKIS levels composed by various object types. Table 3 shows these 17 ATKIS levels and selected object types in the corresponding levels. A complete list of object types can be found in AdV (2012) und BKG (2012, S. 4 ff).

In the ATKIS data, polygons of different ATKIS levels can overlap, e.g. if objects are partly registered by their land cover, but partly by their functions concerning land use. Thus, overlapping object types can be found for mining plants, zoological gardens, recreation and sports areas.

In the dataset made available by BKG, the single ATKIS levels (first eventually including overlapping areas in the original Basis DLM) had been post-processed: By considering a determined optimized sequence (BKG 2012, S. 8), the single layers had been put on top of each other and been simplified to a composed dataset „BDLM_flat“ without overlapping. In addition, a further dataset was available with information on the overlapping areas and their attributes. “BDLM_flat“, concerning the year 2006, was in this form also the basis for BKG for the update process of DLM-DE 2009.

Besides various attributes from the ATKIS assessments, the polygons from BDLM_flat from 2006 contain the attribute CLC_BKG which shows for each polygon a list of all potential CLC classes (e.g. for grassland the potential CLC classes 231, 321 or 141). The attribute CLC_BKG is based on a “semantic transformation table STT” by which all objects of DLM-DE 2009 are marked by a preliminary, partly unique, partly ambiguous CLC code. During the update, this code is supplemented by a unique code in CLC_UPD, which confirms CLC_BKG or modifies it. Basis of the transformation was the adjustment between the definitions of the ATKIS object types (in the old model) and the definitions of the CLC classes (BKG 2012, S. 16).

As BDLM_flat for 2006 had not been updated, the forest areas, for example, could not be related to one of the forest classes 311, 312, 313, 324, due to BDLM_flat. But as the outer boundaries of forest areas showed a quite good registration timeliness, the ATKIS Basis-DLM Flat Layer 2006 provided a quite good basis for the deduction of a forest mask at the status of 2006. In addition, the high timeliness of built-up areas gave the precondition for the derivation of a mask of built-up areas (“built-up mask” or urban mask”) at the status of 2006.

Table 3: Listing of ATKIS levels and selected corresponding areal object types of ATKIS Basis-DLM (old model), which are part of the „Basis-DLM Flat Layer“ 2006 (BDLM-flat 2006). Source: BKG, 2012.

ATKIS level	Content	Object types
SIE02_F	Built-up areas (Basic areas)	2111 Residential area 2112 Industrial area 2113 Areas of mixed use 2114 Areas of special functional character 2202 Leisure Area
SIE03_F	Open space within settlements (Basic areas)	2201 Sports facilities 2213 Cemetery 2227 Green area 2228 Camping ground
SIE04_F	Building structures and other facilities	2301 Mineral extraction site 2304 Drain fields for waste water ......
SIE05_F	Built-up areas (Overlapping areas)	2121 Mining plants 2122 Dump sites 2123 Refinery .....
SIE06_F	Open space within settlements (Overlapping areas)	2211 Open-air theatre 2212 Open-air museum 2221 Stadium 2222 Sports ground ....
VER01_F	Road transport and runways	3101 Road 3102 Way 3103 Place ....
VER02_F	Railway transport	3201 Railway 3202 Cableway ....
VER03_F	Air traffic	3301 Airport 3302 Airfield
VER04_F	Shipping traffic	3401 Port 3403 Shipping line .....

VER05_F	Bridges, tunnels and passages	3513 Tunnel 3514 Bridge ……
VEG01_F	Arable land	4101 Arable land
VEG02_F	Grassland, garden land, heath-land, Moor	4102 Grassland, pasture, meadow 4103 Garden land 4104 Heathland 4105 Moor, bog
VEG03_F	Forest, wood	4107 Forest 4108 Wood
VEG04_F	Special crops, wasteland, bare soils, indeterminable areas for the time being	4109 Special crops 4110 Wasteland 4120 Bare soils …..
VEG05_F	Wetland, wet soils	4111 Wet soils 4106 Swamp, reeds
GEW01_F	Waters	5101 Stream, river, small stream 5102 Canal (shipping) …..
GEW02_F	Facilities and structures on waters	5302 Reservoir, dam 5303 Lock …..
GEW03_F	Special objects in waters, as well as tidal flats, tide ways, harbor basins and lock chambers	3402 Harbor basin 5104 Tide way …..

4.1.2 Digital Land Cover Model DLM-DE 2009

The primary database for the „backdating“ to the year 2006 was the database of the Digital Land Cover Model to the year 2009, DLM-DE 2009, which had also been made available by BKG in the beginning of the project. It describes the topographic objects of the landscape in the vector format under the aspect of land cover / land use (LB/LN) (BKG, 2012), by using the nomenclature of the pan-European database CORINE Land Cover. Basis of the dataset is again ATKIS Basis DLM in the form of the flat layer (without overlapping areas), the „BDLM_flat“. The contributions to it from the 16 federal states had been “frozen” to the date of April 2009. In contrary to the already described dataset BDLM_flat for the year 2006, this input database had been subsequently updated by using various satellite data under the leadership of BKG.

The used satellite image database consisted from satellite images from RapidEye und DMC (Disaster Monitoring Constellation). For the DMC data (ground resolution 32 m), two separated periods for recording had been foreseen, for RapidEye (ground resolution 5 m), a third window had been defined, all within the vegetation period from spring to autumn. Because of unfavorable weather conditions, not all areas of Germany could be covered in 2009. For a percentage of 9% of Germany, additional data from 2010 had to be integrated (BKG, 2012).

4.1.3 CORINE Land Cover 2006 (25 ha MMU)

A further applied vector dataset for the „backdating“ production was the conventionally processed dataset of CORINE Land Cover 2006 (CLC2006) for Germany (Keil et al., 2010a), resulting from GIS supported visual interpretation. The minimum mapping unit (MMU) of this dataset had the value of 25 ha, due to the definition on the European level. CLC2006 had been used mainly as an additional support layer, to serve as a less detailed comparative mapping product for the „look and feel“ impression of the backdating products.

4.1.4 Satellite data Image2006 spring & summer (IRS-P6 LISS-III / SPOT)

The satellite image database for the backdating to the year 2006 consists at first of the IMAGE2006 database which was used for the conventional production of CLC2006 with the minimum mapping unit of 25 ha, or 5 ha concerning changes, respectively. The database IMAGE2006 is composed by a summer coverage and in addition by a spring coverage to provide a better basis for interpretation especially for the differentiation of arable land and grassland in agriculture.

The build-up of the IMAGE2006 database had been performed centrally for all member states by ESA, supported by EU funds. As the Landsat-7 ETM+ system had some malfunctions leading to only a very restrictive usability of Landsat-7 data, satellite images of the Indian IRS-P6 LISS-III system and the systems of SPOT-4 HRVIR and SPOT-5 HRG had been used. The satellite images had been ortho-rectified centrally on behalf of ESA at the Remote Sensing Technology Institute (IMF) of DLR, the second institute of the Earth Observation Center (EOC) in Oberpfaffenhofen (Müller et al., 2007). The multispectral products were delivered to all member states in a spatial resolution of 20 m in the requested national projection. In Germany, the Gauss-Krueger projection with Bessel ellipsoids was applied.

As the swath width of IRS-P6 LISS-III is 140 km (in comparison to about 180 km for Landsat), for the SPOT sensors even only 60 km, the database of IMAGE 2006 is much more inhomogeneous as e.g. the IMAGE2000 database for CLC2000 (which was based on Landsat-7 ETM+ and Landsat-5 TM data).

4.1.5 Satellite data Landsat-5 summer

In order to build on a homogeneous data basis for an as far as possible automatic processing approach, a further data basis was collected besides IMAGE2006 (IRS-P6 LISS-III and SPOT images), consisting of Landsat-5 TM images. NASA and US Geological Survey reacted after the partial malfunctions of Landsat-7 (malfunction of the „Scan Line Correctors“ (SLC) in Mai 2003; NASA, 2011) by an intensified recording and processing of Landsat-5 Thematic Mapper data. However, more or less only data from the summer season 2006 could be found in the archives of the US Geological Survey. The Landsat data are freely available without costs and can be downloaded from the USGS archive in an ortho-rectified form in a good quality. For the inquiry, the use of GLOVIS is recommended, the “Global visual system” of USGS (USGS, 2014). The Landsat data are available in a pixel solution of 30 m by 30 m and are present in the UTM system of the particular valid USGS zone, in Germany in UTM coordinates of UTM zone 32.

Besides the Landsat database at the status of 2006, a Landsat database for the year 2009 was built-up as well; these images were not included in the processing scheme, but were used in special situations for comparisons with the DLM-DE 2009 vector data and the other satellite images. A table with the characteristics of the various satellite images can be found in table 4.

4.1.6 Satellite data IRS-P6 AWiFS 2005 / 2006 multi-seasonal

For the assessment of change areas between 2006 and 2009, changes within the agricultural areas play an important role. This makes the separation of arable land against grassland necessary regarding the reference year 2006. The delimitation of grasslands and arable land is very difficult, when only one image is available. Various pre-studies showed the high value of using multi-seasonal satellite data for this problem (Metz, 2009; Keil et al, 2010). Information on the phenology and the vegetation dynamics facilitate to separate the arable areas (characterized by a temporally higher soil amount) from grassland areas, showing lower dynamics concerning the green vegetation cover, as discussed in Keil et al (2010c) and Esch et al. (2014 a, 2014 b).

The Indian system of IRS-P6 AWiFS proved to be a suitable compromise between high temporal availability and still sufficient geometric resolution (of 60 m by 60 m) for these tasks. IRS-P6 (also referred to as ResourceSat 1) carries the AWiFS sensor besides the LISS-III sensor (swath width 140 km multispectral bands). AWiFS covers strips of 360 km width both on the left and to the right of the nadir line, covering together a swath of 700 km.

Because of the high overlapping of records from neighboring orbits, the chances for cloud-free image parts at different vegetation seasons are highly increased (about 3 to 6 records per year). By three to five record dates along the vegetation period, the application of “phenological signatures”, depending on the position of these dates, support much the separation of arable land and grassland. This could be demonstrated also in the EUROLAND Grassland subproject as part of Geoland2 (Brodsky et al, 2012). The multi-seasonal potential of satellite data was used also for the production of the Pan-European „High Resolution Grassland-Layer“ 2012 (Zillmann et al., 2014).

Table 4: Specifications of the used satellite systems (Beule et al., 2004, modified)

Satellite	Sensor	Bands	Spatial resolution (m)	Swath width (km)	Repetition rate (days)	Start date
Landsat-5	TM (Thematic Mapper)	VIS-B	30	185	16	03-1984
		VIS-G	30			
		VIS-R	30			
		NIR	30			
		SWIR	30			
		TIR	120			
		SWIR	30			
SPOT 4	HRVIR (High Resolution Visible and Infrared)	PAN	10	60	26 (1-4)	03-1998
		VIS-G	20			
		VIS-R	20			
		NIR	20			
		SWIR	20			
SPOT 5	HRG (High Resolution Geometric)	PAN (x2)	5 (2.5)	60	35 (1-4)	05-2002
		VIS-G	10			
		VIS-R	10			
		NIR	10			
		SWIR	20			
IRS-P6 (Resource-Sat 1)	LISS-III (Linear Imaging Self-Scanning System)	VIS-G	23.5	140	24	10-2003
		VIS-R	23.5			
		NIR	23.5			
		SWIR	70.5			
	AWiFS (Advanced Wide Field Sensor)	VIS-G	58	740	24	
		VIS-R	58			
		NIR	58			
		SWIR	58			

By preliminary analyses of so-called „quicklooks“ (downsized satellite images) of the available AWiFS scenes, it resulted, that suitable multi-seasonal scenes (two in spring, one in mid-summer, one in late summer) were not available for all regions in Germany in 2006 alone. Therefore, multi-seasonal AWiFS scenes of two years, 2005 and 2006, were purchased. For missing spring scenes because of the cloud cover situation in the one year, information on the spring aspect could be integrated by spring scenes of the other year.

As the contingent of ESA was exhausted concerning the supply of AWiFS scenes within the Copernicus (GMES) „Data Access Portfolio“, the 43 AWiFS scenes necessary for a multi-seasonal coverage of Germany in 2005 / 2006 were procured using project funds from the present project.

4.1.7 Soil Sealing Layer 2006 with & without mineral extraction sites /construction sites

A further information layer covering whole Germany is the product of „Soil Sealing“ for the reference year 2006, available in two versions. The layer had been produced by satellite data of the IMAGE2006 database (IRS-P6 LISS-III and SPOT images), it characterizes the built-up areas in the member states of the European Environment Agency by the degree of soil sealing between 1% and 100%. The original pixel spacing is 20 m by 20 m; besides that, an averaged degree of sealing exists on a grid of 100 m by 100 m.

The first version of the soil sealing layer had been produced in the frame of the „GSE Fast Track Service“. It can be downloaded via the web portal of EEA under “EEA Fast Track Service Precursor on Land Monitoring – Degree of soil sealing” (EEA, 2009; EEA, 2010). This first version product contains, besides built-up areas, also mineral extraction sites and still open construction sites which show a similar spectral behavior as built-up areas.

Besides this first version of the Soil Sealing Layer 2006, a further, a revised version was available at DFD. This product, named by EEA as “Revised Soil Sealing 2006, degrees of sealing 20m and 100m”, had been completely reworked, together with a derivation of an updated degree of sealing for the year 2009, “Imperviousness 2009, degrees of imperviousness 20m and 100m” (EEA, 2010; Gangkofner et al., 2010). This revised version, supported by inputs of the various member states, does not any more include the areas of extraction sites of gravel, sand or lignite, as these areas present in the most cases not the characteristics of sealed areas, concerning the runoff characteristics of precipitation water. Concerning the thermal characteristics, they show more similar behavior.

By comparing the two products descended from the different specifications of product versions, possibilities result to extract information concerning the distribution of mineral extraction sites and construction sites.

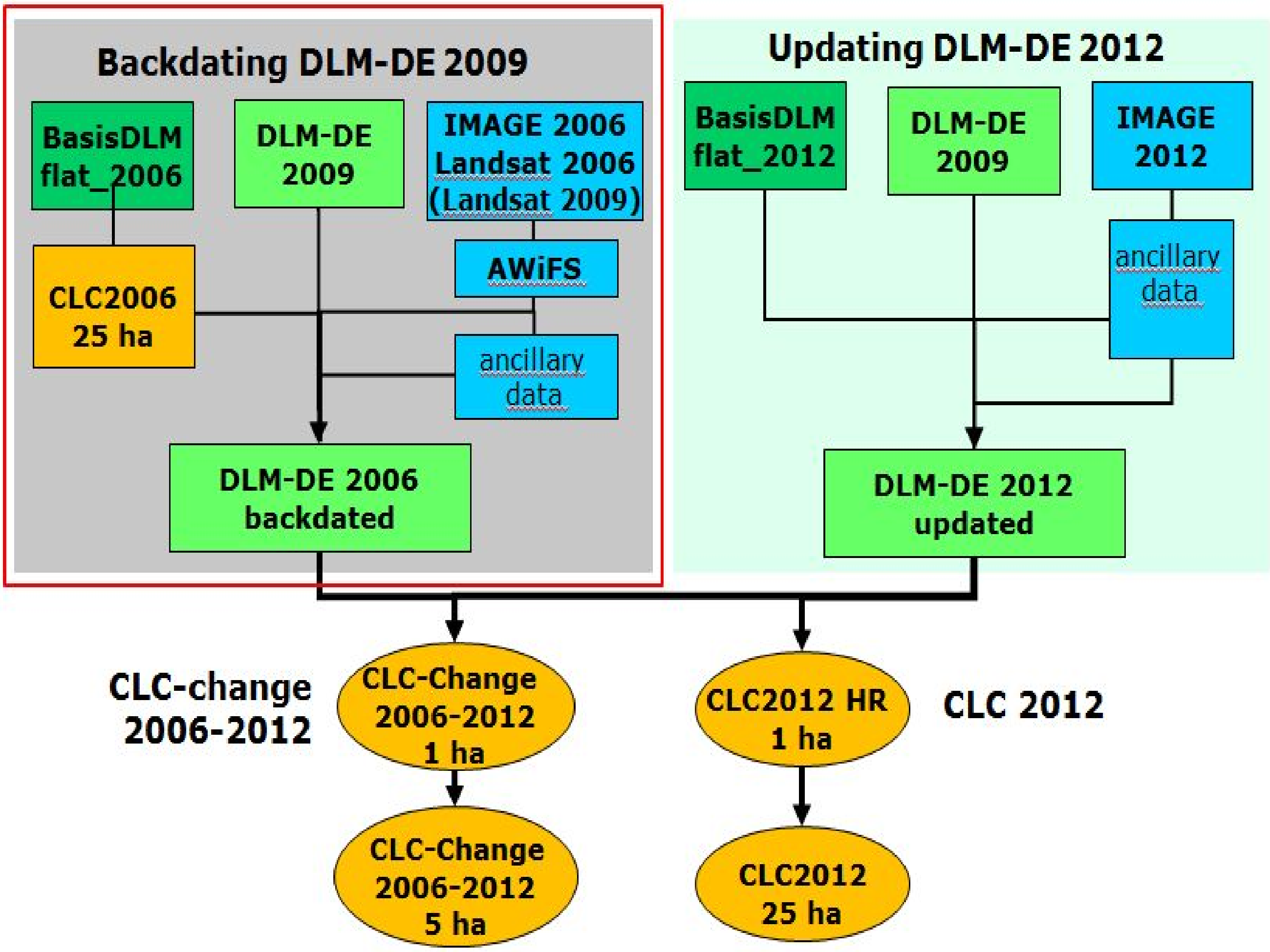
4.1.8 Further regional available data

As part of the geo-service developments of the “GMES service elements“, the project „GSE Forest Monitoring“ had been performed under the leadership of GAF AG in Munich. It comprised service developments in the field of forestry, but also under viewpoints of ecology (GSE Forest Monitoring, 2010). In the context of the deduction of land cover in Germany, maps of forest cover are available for the new federal states, for Schleswig-Holstein and for parts of Baden-Württemberg, presenting the categories deciduous forest, coniferous forest and mixed forest, based on satellite data of (mainly) 2005. The data were made available by GAF AG for the project via intermediation of UBA.

The information on forest cover from the GSE Forest Monitoring Project was included in the “backdating” project mainly as supplementary support data, after some methodological investigations for a direct integration.

A summary of the data flows and processing steps (as part of the total project of CLC2012) is shown in Figure 8. Two main tasks are visible: The task of updating for the description of the status in the year 2012, and the task of backdating as a part of the task for the deduction of changes between 2006 und 2012 (product „CLC-Change“). The updating (data flows shown on the right) was performed as explained before by BKG.

Figure 8: The two tasks of updating and backdating during the production of CLC2012 and CLC-Change (2006 – 2012) showing also the related data flows. The task of backdating (red outlines) was covered by DLR-DFD, the other tasks of updating and the generalization were done under the responsibility of BKG. Source: BKG presentation at the kickoff meeting of „CLC Backdating" at 27-09-2012, modified.



4.2 Data situation

4.2.1 Data situation concerning the LISS-III and Landsat-5 TM datasets

Concerning the LISS-III data inside the IMAGE2006 database, it had been intended for CLC2006 to reach the summer and spring coverage as far as possible in the reference year 2006, together with images of SPOT-4 and SPOT-5. But for Germany it became clear that for a mainly cloud-free coverage, scenes from 2005, 2006 and 2007 were necessary. In the present project, the preference was given to the LISS-III data because of the larger swath width of 120 km in comparison to 60 km concerning the SPOT systems.

For the spring coverage, 15 scenes were used from 2005, 8 scenes from 2006 and 23 scenes from 2007. For the summer coverage, 15 scenes were selected from 2005 and 29 scenes from 2006. In addition, the implementation of small sub-scenes from 17 SPOT images was necessary for spring and also of various sub-scenes from 14 SPOT and 7 Landsat images for summer, in order to close data gaps resulting from cloud problems. As far as possible, the scene which was acquired next to the reference date of 1st of July 2006 was used for the mosaic generation of spring and summer coverage. Because of clouds and haze, it happened some times that neighboring scenes had a difference of acquisition time of up to 2 years. This effect could lead to some consistency problems, e.g. in the situation of mineral extraction sites connected with high dynamics.

The database of Landsat-5 Thematic Mapper was built-up in supplement to the summer database of LISS-III, in order to have available larger homogeneous regions, especially in the forest areas, for the subdivision of forest classes. Alltogether, about 90 already ortho-rectified Landsat scenes from the archive of US Geological Survey were downloaded and composed to multi-spectral image products. About 40 different Landsat images from 2006 were integrated in the Landsat image mosaics with summer aspect.

An estimate of data gaps in the three high resolution image mosaics resulting from clouds, cloud shadows and haze resulted in the following percentages concerning the whole area of Germany:

- Spring data of IMAGE2006 (primarily LISS-III): about 0,66 % data gaps
- Summer data of IMAGE2006 (primarily LISS-III): about 0,83 % data gaps
- Summer data of Landsat-5 TM: about 0,38 % data gaps

In the spring scenes, also snow cover led to data gaps which are also integrated in the estimated percentages.

4.2.2 Data situation concerning the multi-seasonal AWiFS data

Concerning the multi-seasonal database of IRS AWiFS to the reference year 2006, coverages of four to five periods were planned originally, from the beginning to the end of the vegetation cycle of 2006. But it turned out that for spring 2006 nearly no cloud-free parts were recorded in many regions of Germany, especially for the important early vegetation period in March / April; partly that was valid also for May. On the other hand, in large regions of Germany, a cloud-free coverage was available for mid of July and also beginning and mid of September. A turn to the year 2005 would have delivered an excellent coverage for the period of beginning April, to a high extent also for end of May, and also a nearly cloud-free coverage of early and mid of September. But the mid-summer period of mid to end of July delivered a complete failure of coverage due to weather conditions, and this period resulted to be an important date for arable / grassland discrimination due to former studies (Metz 2009; Keil et al. 2010c).

Therefore, it was aimed at a combination of suitable periods in 2005 and 2006 for the coverage of Germany, under the premise that robust measures of vegetation dynamics were to be used which were significant also for a two-year cycle.

An overview of the ordered 43 AWiFS scenes for 2005 (3 periods) and for 2006 (4 periods) is shown in Figure 9 and Figure 10.

The application to include the IRS-P6 AWiFS data in the Copernicus (GMES) „Data Access Portfolio“, supported by EEA, could unfortunately not positively be responded by ESA. Therefore, the data provision was integrated in the UBA project.

Six of the selected scenes were already available at DFD from the DAP contingent DAP_MG2_04, used in the GMES Geoland2 project for the task „European Land Cover of Forests“ and the investigations on the HR Grassland Layer. These scenes are marked in blue in Figure 9 and Figure 10. Therefore, at first 36 scenes due to Table 5 were ordered at the company of EUROMAP.

Figure 9: The selected scenes of IRS-P6 AWiFS for the year 2005. Source: Euromap / GAF AG (Overlay produced 2012 by Euromap GmbH).

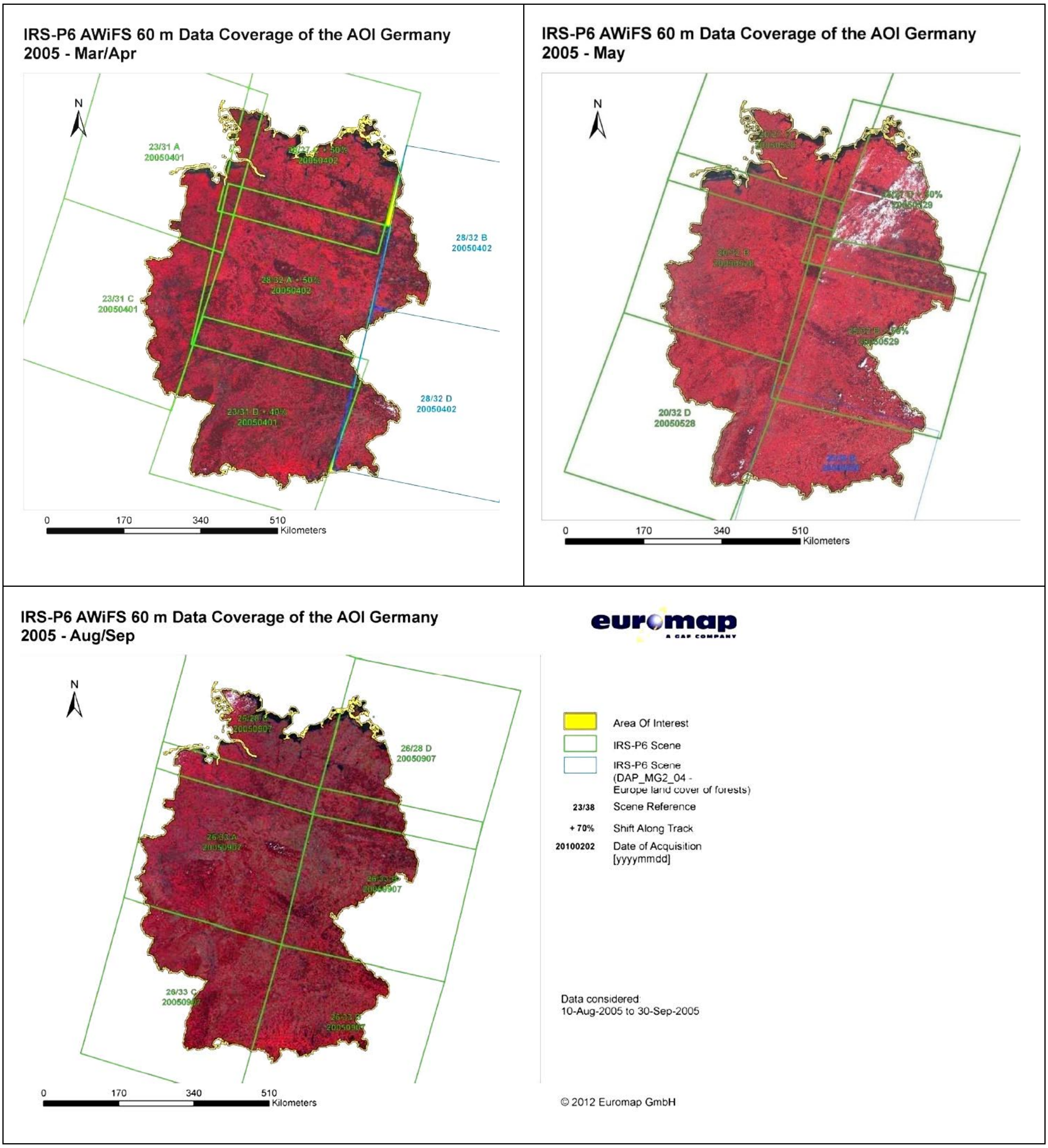


Figure 10: The selected scenes of IRS-P6 AWiFS for the year 2006. Source: Euromap / GAF AG (Overlay produced 2012 by Euromap GmbH).

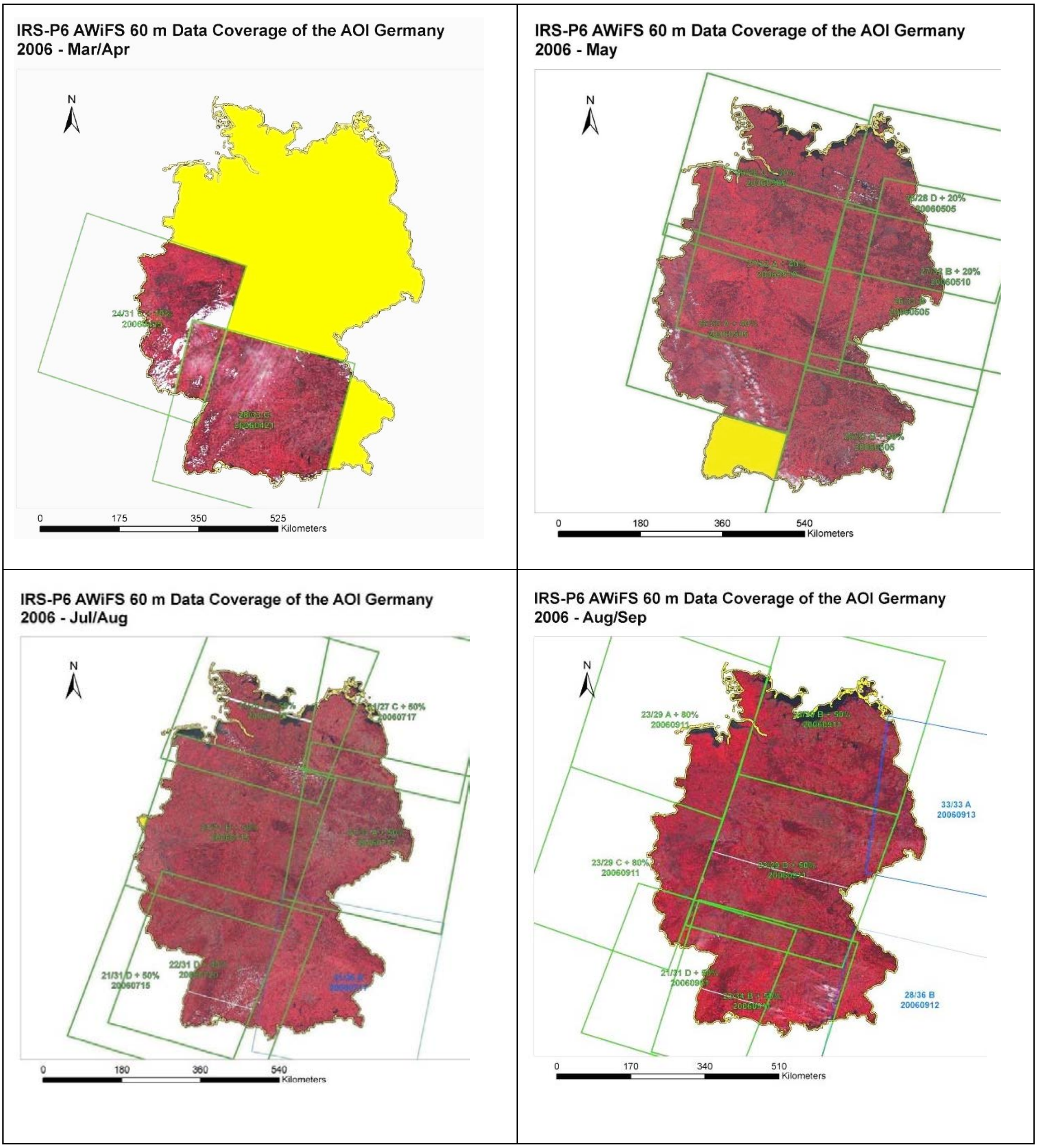


Table 5: Overview of the AWiFS scenes ordered in the first margin

Time window	Mission	Sensor	Path	Row	Subscene	Shift	Date
2006 August / September	IRS-P6	AWiFS	21	31	D	50	20060901
			23	29	C	70	20060911
			23	29	B	50	20060911
			23	29	D	50	20060911
			23	34	B	50	20060911
2006 July / August	IRS-P6	AWiFS	21	26	D	50	20060715
			21	31	B	50	20060715
			21	31	D	50	20060715
			22	31	D	40	20060720
			31	27	C	50	20060717
			31	32	A	50	20060717
2006 May	IRS-P6	AWiFS	26	28	D	20	20050505
			26	33	B	0	20050505
			26	33	B	90	20050505
			27	32	B	20	20050505
			26	28	C	30	20050510
			26	33	A	40	20050505
			27	32	A	40	20050505
2006 March / April	IRS-P6	AWiFS	24	31	C	10	20060425
			28	33	C	0	20060421
2005 August / September	IRS-P6	AWiFS	26	28	C	0	20050907
			26	28	D	0	20050907
			26	33	A	0	20050907
			26	33	B	0	20050907
			26	33	C	0	20050907
			26	33	D	0	20050907

2005 May	IRS-P6	AWiFS	20	27	D	0	20050528
			20	32	B	0	20050528
			20	32	D	0	20050528
			25	27	D	50	20050529
			25	32	B	50	20050529
2005 March / April	IRS-P6	AWiFS	23	31	A	0	20050401
			23	31	C	0	20050401
			23	31	D	40	20050401
			28	27	C	50	20050402
			28	32	A	50	20050402

During the project it turned out that the pre-processing steps of the scenes from DAP_MG2_04 resulted in higher differences in relation to the other scenes, especially concerning geometry, which would have meant a post-processing and a significant additional work load during the combined evaluation together with other information products. In addition, the partly shifted scenes in relation to the original standard quarter scenes did not fit any longer in a sufficient way. Therefore, these six scenes were ordered again after consultation with UBA in the way of the first order, in order to get a homogeneous AWiFS data basis. A seventh scene was included as well, planned first to be substituted by a Landsat product of a similar date, because of homogeneity reasons.

The supplementary data acquisition is listed in Table 6.

Table 6: Overview of the AWiFS scenes ordered in the second margin

Time window	Mission	Sensor	Path	Row	Subscene	Shift	Date
2006 August / September	IRS-P6	AWiFS	23	29	A	80	20060911
			28	32	B	10	20060912
			28	32	D	10	20060912
2006 July	IRS-P6	AWiFS	31	32	C	50	20060717
2005 May	IRS-P6	AWiFS	25	32	D	30	20050529
2005 March / April	IRS-P6	AWiFS	28	32	B	10	20050402
			28	32	D	10	20050402

5 Methodic approach

5.1 Applied software tools

For data processing and the GIS supported interactive data interpretation, five different software systems were used:

- **CATENA:** For various steps of satellite data pre-processing, the processing system CATENA of the neighboring institute of DFD, the Remote Technology Institute IMF, was employed. CATENA was used especially for the ortho-rectification of satellite images, especially of the AWiFS data.
- **ERDAS Imagine:** For various steps of image processing, the ERDAS Imagine was applied in the version 2011. Thus, the satellite image mosaics for the macro-regions were built-up by ERDAS Imagine. The moduls of ERDAS modeler were used for the derivation of various thematic information layers.
- **ArcGIS 10:** The GIS Software ESRI ArcGIS version 10.0 and 10.1, respectively, was used for the GIS related tasks and the manual post-processing of deduced changes in relation to 2009. Several GIS models and python scripts, developed within the project, were part of the GIS activities.
- **eCognition:** For the derivation of new object borders by segmentation out of the satellite images, the image processing system „eCognition“ was employed in the version eCognition Developer version 64. The eCognition Developer enables a combined segmentation and classification on the object level. Also semantic combinations of different fine-scale segmentations are possible (Esch et al, 2008). An important aspect used for the segmentation is the specification of a „segment sceleton“, for which in the project the vector geometry of the ATKIS Basis-DLM (flat layer) was used. This „segment sceleton“ was then intersected in more details by integrating information from the remote sensing products. The deduced segments could also be exported into the ESRI Shape vector format for further GIS processing.
- **IDL:** The „Interactive Description Language“ IDL (in the version 7.1 and 8.1, respectively) was applied for the calculation of zonal statistics, by overlaying the deduced thematic layers and the polygon layers previously transferred into raster data.

5.2 Approach for the assessment of main change processes

In order to derive the backdating dataset back to the year 2006, based on DLM-DE 2009, the most important change classes were to be regarded, meaning to investigate especially the primary change processes in the nomenclature of CORINE Land Cover. For the categorization of change class relevance, deduced statistics from CLC2006_Change were suitable which contain the areal sums of the most frequent changes, sorted by these areal sums and reporting on the importance of these changes within the overall distribution.

In Table 7, the most frequent 46 change classes in Germany between 2000 and 2006 are listed (Keil et al., 2010a), showing the areal sums in ha and as percentages in regard of the total change area.

The far right column includes the percentage of cumulation, the left column the rank concerning the areal percentage. Regarding 46 change classes, about 90% of the change areas between 2000 and 2006 are covered. Regarding 27 change classes, these classes would cover already about 80% of CLC change areas. In consultation of UBA, it was decided to perform the “backdating” in a cost-effective manner, and not to spent unnecessary resources on change classes having negligible weight of interest.

The change classes are grouped in nine categories of change processes, displayed in different colors. When regarding the first five change classes, three of them are connected with change processes on the forest areas. With the biggest portion of total change area, the change class with the transition 312 -> 324 is in the first place (coniferous forest is transformed to transitional woodland-shrubs), a change class which is connected with the large storm damages between 2000 and 2006 in Germany. In place 2, the change class 231 -> 211 can be found, the transition from arable land to grassland in agriculture, followed by the change class 211 -> 112, the transition from arable land to discontinuous urban fabric. Place 6 is the position of the change class 211 -> 131, the generation of new open mining areas on former arable land. These 6 change classes in CLC2006_Change cover already 44% of change areas. This points out that a “process oriented approach”, starting from the main change processes, makes sense regarding an automatic method as far as possible.

Table 7: The dominating 46 change classes due to „CLC_Change“ between 2000 and 2006 in Germany (Source: Keil et al 2010a; concerning the meaning of CLC classes see Figure 1).

Legend:

Intensification in agriculture
Extensification in agriculture
Afforestation
Areas with forest loss
Urbanisation / Increase of soil sealing
New extraction sites
Recultivation of extraction sites
New water bodies
Other change

Rang No.	Transition	Germany		
		Area[km²]	Percent age	Cumu-lated
1	312 → 324	265.30	11.77%	11.77%
2	231 → 211	192.87	8.56%	20.33%
3	211 → 112	178.61	7.92%	28.25%
4	324 → 313	157.95	7.01%	35.26%
5	324 → 312	117.93	5.23%	40.49%
6	211 → 131	86.09	3.82%	44.31%
7	133 → 112	77.81	3.45%	47.76%
8	211 → 121	77.21	3.43%	51.18%
9	324 → 311	54.00	2.40%	53.58%
10	333 → 512	51.03	2.26%	55.84%
11	211 → 133	48.11	2.13%	57.98%
12	131 → 324	46.79	2.08%	60.05%
13	131 → 512	42.37	1.88%	61.93%
14	133 → 121	41.72	1.85%	63.78%
15	333 → 324	39.54	1.75%	65.54%
16	242 → 112	37.29	1.65%	67.19%
17	231 → 242	36.98	1.64%	68.83%
18	231 → 112	36.16	1.60%	70.44%
19	211 → 231	35.02	1.55%	71.99%
20	211 → 142	26.22	1.16%	73.15%
21	312 → 131	24.52	1.09%	74.24%
22	313 → 324	24.29	1.08%	75.32%
23	131 → 211	23.43	1.04%	76.36%
24	333 → 231	23.12	1.03%	77.38%
25	131 → 333	22.06	0.98%	78.36%
26	211 → 512	21.45	0.95%	79.31%
27	324 → 131	20.29	0.90%	80.21%
28	331 → 423	19.98	0.89%	81.10%
29	131 → 231	18.47	0.82%	81.92%
30	321 → 324	17.60	0.78%	82.70%
31	333 → 321	16.87	0.75%	83.45%
32	222 → 211	13.97	0.62%	84.07%
33	231 → 121	12.86	0.57%	84.64%
34	133 → 122	11.62	0.52%	85.16%
35	231 → 411	11.47	0.51%	85.66%
36	242 → 211	11.00	0.49%	86.15%
37	242 → 121	9.43	0.42%	86.57%
38	231 → 131	9.12	0.40%	86.98%
39	231 → 512	9.02	0.40%	87.38%
40	231 → 324	8.66	0.38%	87.76%
41	133 → 211	8.07	0.36%	88.12%
42	133 → 231	7.60	0.34%	88.46%
43	231 → 133	7.40	0.33%	88.78%
44	211 → 122	7.32	0.32%	89.11%
45	311 → 324	7.31	0.32%	89.43%
46	242 → 231	7.19	0.32%	89.75%

A repositioned sequence of these 46 change classes points at the aim of the applied procedure. When grouping the participating transition classes by the status in the year 2006, it can be derived which classes build the relevant CLC classes in 2009 concerning the development from 2006 on. It is also obvious in which amount these change classes and groups contribute to the total change area. The information on that is divided into two tables, Table 8 and Table 9. In addition, in a fourth column, an associated thematic layer to the status 2006 is listed by the CLC class identifier. Partially, it is indicated from which kind of information source the associated thematic raster layer can be derived.

After a derivation of the dominant CLC classes at the state of 2006 (in raster information), it can be stated, using the geometries of DLM-DE2009 polygons, which polygons have contributions from other CLC classes in comparison to 2009, and can thus lead to change areas between 2006 and 2009. For the necessary subdivision of the concerning polygons, segmentation methods can be used which are built at information from the IMAGE2006 database (having a pixel spacing of 20 m).

In the following, the various groups of change classes are described in more detail.

5.2.1 The groups of change classes

For the group of change classes in the context of mineral extraction sites in 2006 (CLC class 131, transitions 131 -> xxx, see Table 8), the first topic is to derive a thematic raster layer for mineral extraction sites with about 1 ha MMU. A corresponding data basis is available by the “Soil Sealing Layer 2006” with much better geometric details than in the conventional CLC2006, as there exist two versions, one with, one without the areas of mining areas and construction sites (see chapter 4.1.7).

Also for the group of change classes related to the status of construction sites (133), it can be benefited by the two variants of the sealing layer.

The agricultural classes 211 and 231 (arable land and grassland / pasture land) participate in the change processes to a larger extent, on both within agricultural areas, as well as in transitions towards other classes, eg. in urban development (as in the transitions 211 -> 121, 231 -> 112, see Table 8 and Table 9). According to the results of the preliminary study (Keil et al., 2010 c, Metz, 2009), multi-seasonal time series e.g. from IRS-P6 AWiFS contain the potential to perform the delimitation of arable land and grassland to a larger part automatically. The dynamics of growth development, including the harvesting stage is shown quite well in temporal descriptions of the vegetation index NDVI (Rouse et al., 1973). After an appropriate pre-processing with respect to a suitable geometry of the satellite data and the creation of multi-temporal levels in corresponding mosaics, parameters of the temporal statistics should help to achieve the delimitations of arable land and grassland.

Concerning the change classes in connection with forest distribution and forest development, two groups of change processes can be identified (Table 9).

The change class with the largest single contribution, 312 → 324, points with a share of 11% of all changes to the large amount of storm damages that often make the coniferous forest particularly violent. Here it will be the task to derive on the one hand with a thematic layer the fine distribution of intact older coniferous forest stands (312) or stable other forest stands, and on the other hand forest - shrub transition stages (324) already existing in 2006 after clearing, removal of storm damaged areas or reforestation. A support will come from the ATKIS based general forest mask (ATKIS Basis-DLM flat layer, see section 4.1.1).

Another extensive land development is the transition starting from reforestation areas, e.g. from previous storm damaged areas and reforestation/afforestation into the categories of older forest stands. The transitions 324 - > 31x between 2000 and 2006 delivered nation-wide an amount of more than 14.5 % of the change areas. For these processes, including also continuous transitions of the class 324 to the forest classes 311, 312 and 313 (not always clearly to be detected), also the 324 areas assessed in the conventional CLC2006 have to be regarded.

There are some transitions which play a specific role, having their origin in 2006 in the CLC classes 222 (permanent fruit trees and berry plantations), 331 (beaches, dunes, sandy areas), 333 (sparsely vegetated areas), and 321 (semi-natural grassland). These categories can only be separated with difficulties from other CLC classes by automatic approaches, but they occur only in specific regions and in specific contexts. Thus, the category 333 occurs especially in the context of large-area extraction sites and during the first steps of the re-cultivation of abandoned mineral extraction sites, but also in the context of inoperative or operative military training sites.

Table 8: The 46 change classes grouped due to CLC classes in 2006, part 1 (concerning the abbreviations of CLC classes, see Figure 1).

Process	2006	2009	2006 - Thematic raster layer	2006 - Thematic raster layer - Meaning	Area km2 (2000-2006)	Percentage (2000-2006)	Cumulated (2000-2006)
131 → 211	131	211	131 Layer	**Mineral extraction sites**	23.43	1.04%	6.80%
131 → 231	131	231	131 Layer		18.47	0.82%	
131 → 324	131	324	131 Layer		46.79	2.08%	
131 → 333	131	333	131 Layer		22.06	0.98%	
131 → 512	131	512	131 Layer		42.37	1.88%	
133 → 112	133	112	133 Layer	**Con-struction sites**	77.81	3.45%	6.52%
133 → 121	133	121	133 Layer		41.72	1.85%	
133 → 122	133	122	133 Layer		11.62	0.52%	
133 → 211	133	211	133 Layer		8.07	0.36%	
133 → 231	133	231	133 Layer		7.6	0.34%	
222 → 211	222	211	prep. coarse 222 Layer CLC	**Permanent crops**	13.97	0.62%	0.62%
333 → 231	333	231	prep. coarse 333 Layer CLC	**Areas with sparse vegetation**	23.12	1.03%	5.79%
333 → 321	333	321	prep. coarse 333 Layer CLC		16.87	0.75%	
333 → 324	333	324	prep. coarse 333 Layer CLC		39.54	1.75%	
333 → 512	333	512	prep. coarse 333 Layer CLC		51.03	2.26%	
331 → 423	331	423	prep. coarse 331 Layer CLC	**Beaches. dunes. sandy areas**	19.98	0.89%	0.89%
242 → 112	242	112	*(not relevant)*	*(not relevant for 1 ha MMU. as then 211 or 231)*	37.29	1.65%	2.88%
242 → 121	242	121	*(not relevant)*		9.43	0.42%	
242 → 211	242	211	*(not relevant)*		11	0.49%	
242 → 231	242	231	*(not relevant)*		7.19	0.32%	

Table 9: The 46 change classes grouped due to CLC classes in 2006, part 2 (concerning the abbreviations of CLC classes, see Figure 1).

Process	2006	2009	2006 - Thematic raster layer	2006 - Thematic raster layer - Meaning	Area km2 (2000-2006)	Percent age (2000-2006)	Cumu-lated (2000-2006)
211 ⇢ 112	211	112	211 Layer from temp. statistics	Arable land (non irrigated)	178.61	7.92%	21.28%
211 ⇢ 121	211	121	211 Layer from temp. statistics		77.21	3.43%	
211 ⇢ 122	211	122	211 Layer from temp. statistics		7.32	0.32%	
211 ⇢ 131	211	131	211 Layer from temp. statistics		86.09	3.82%	
211 ⇢ 133	211	133	211 Layer from temp. statistics		48.11	2.13%	
211 ⇢ 142	211	142	211 Layer from temp. statistics		26.22	1.16%	
211 ⇢ 231	211	231	211 Layer from temp. statistics		35.02	1.55%	
211 ⇢ 512	211	512	211 Layer from temp. statistics		21.45	0.95%	
231 ⇢ 112	231	112	231 Layer from temp. statistics	Grassland (pastures)	36.16	1.60%	14.39%
231 ⇢ 121	231	121	231 Layer from temp. statistics		12.86	0.57%	
231 ⇢ 131	231	131	231 Layer from temp. statistics		9.12	0.40%	
231 ⇢ 133	231	133	231 Layer from temp. statistics		7.4	0.33%	
231 ⇢ 211	231	211	231 Layer from temp. statistics		192.87	8.56%	
231 ⇢ 242	231	242	231 Layer from temp. statistics		36.98	1.64%	
231 ⇢ 324	231	324	231 Layer from temp. statistics		8.66	0.38%	
231 ⇢ 411	231	411	231 Layer from temp. statistics		11.47	0.51%	
231 ⇢ 512	231	512	231 Layer from temp. statistics		9.02	0.40%	
321 ⇢ 324	321	324	prep. coarse 321 Layer CLC	Natural grassland	17.6	0.78%	0.78%
311 ⇢ 324	311	324	prep. coarse 311 Layer CLC	Deciduous forest	7.31	0.32%	0.32%
312 ⇢ 131	312	131	*(manually in forest mask 2006)*	Coniferous forest	24.52	1.09%	12.86%
312 ⇢ 324	312	324	detail. 324 / 312 Layer 2006		265.3	11.77%	
313 ⇢ 324	313	324	prep. coarse 313 Layer CLC	Mixed forest	24.29	1.08%	1.08%
324 ⇢ 131	324	131	detail. 324 / 312 Layer 2006	Transitional woodland - shrub	20.29	0.90%	15.54%
324 ⇢ 311	324	311	detail. 324 / 312 Layer 2006		54	2.40%	
324 ⇢ 312	324	312	detail. 324 / 312 Layer 2006		117.93	5.23%	
324 ⇢ 313	324	313	detail. 324 / 312 Layer 2006		157.95	7.01%	

Within the chosen automatic approach for backdating, the corresponding categories of CLC2006 (25 ha MMU) were to be integrated in a corresponding thematic raster layer in a first step. During the steps of manual checks and improvements, especially in the primary distribution areas (e.g. concerning fruit cultivation areas, CLC class 222), smaller partial areas could be integrated in the change layer.

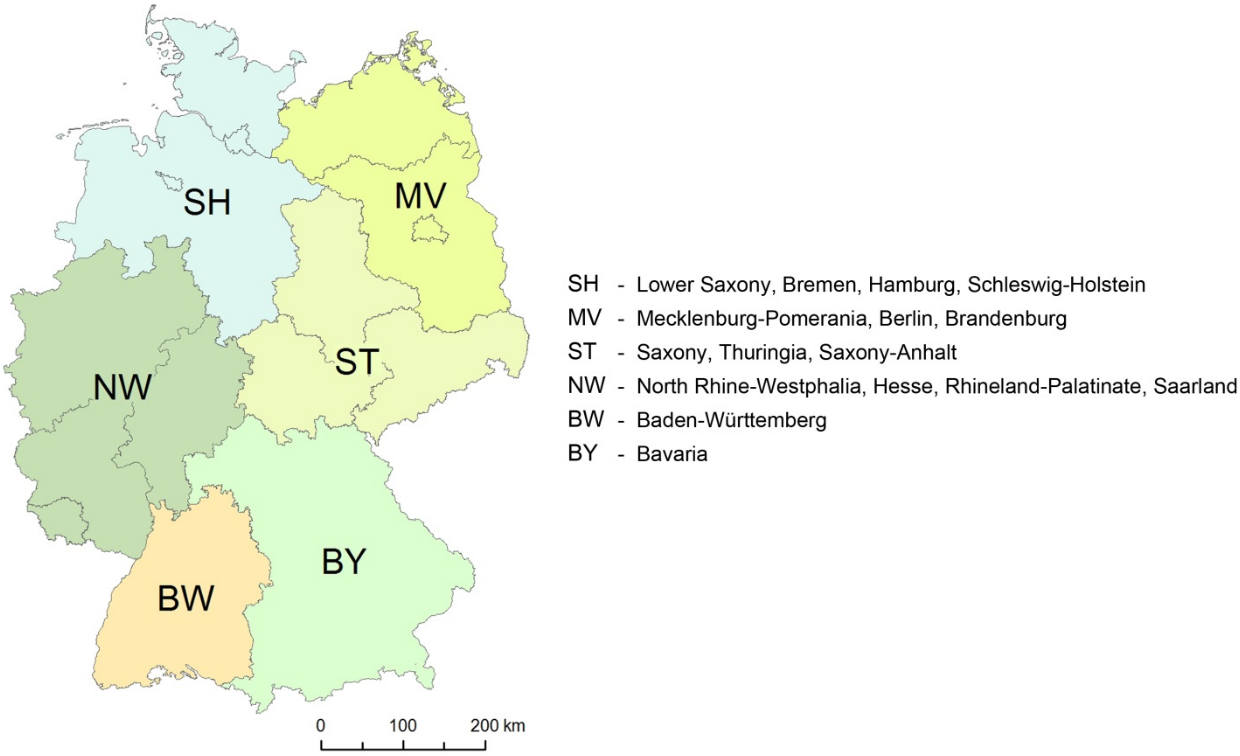
Concerning the primary 46 change areas between 2000 and 2006, four transitions play a larger role which start from heterogeneous agricultural areas 242, the transitions of 242 -> 112, 242 -> 121, 242 -> 211 and 242 -> 231 (see Table 9). It has to be taken into account that these categories play a larger role for an assessment with a MMU of 25 ha, but not in the context of DLM-DE_Backdating with a MMU of 1 ha. In a smaller extent, 242 polygons are also defined in DLM-DE2009, but mainly in closely related contexts of the classes 222, 231 and 211. In the table, the lines with the corresponding transitions are supplemented by the note “not relevant”.

5.3 Pre-processing of the data

5.3.1 Split into six macro-regions

After first small-scale studies on how to proceed in the project, the total area of the Federal Republic of Germany was divided into six macro-regions as processing units, each involving groups or individual representations of federal states. This division was explicit so far (and without additional separation of polygons possible), because the overall record of the DLM-DE2009 for each polygon had an assignment to a federal state, and also the BDLM-DE_flat (2006) existed separately for the states. The division into the macro-regions and their composition is shown in the Figure 11.

Figure 11: Split of Germany into six macro-regions



5.3.2 Mosaicking of IMAGE2006 summer and spring scenes

The spring and summer scenes of the IMAGE2006 data base are a primary data basis for the derivation of the land cover status by the year 2006. With the geometric resolution of 23 m by 23 m and the pixel size of 20 m by 20 m, these data are to be the base of segmentation, or better of sub-segmentation of polygons from DLM-DE 2009, for which potential changes are to be regarded.

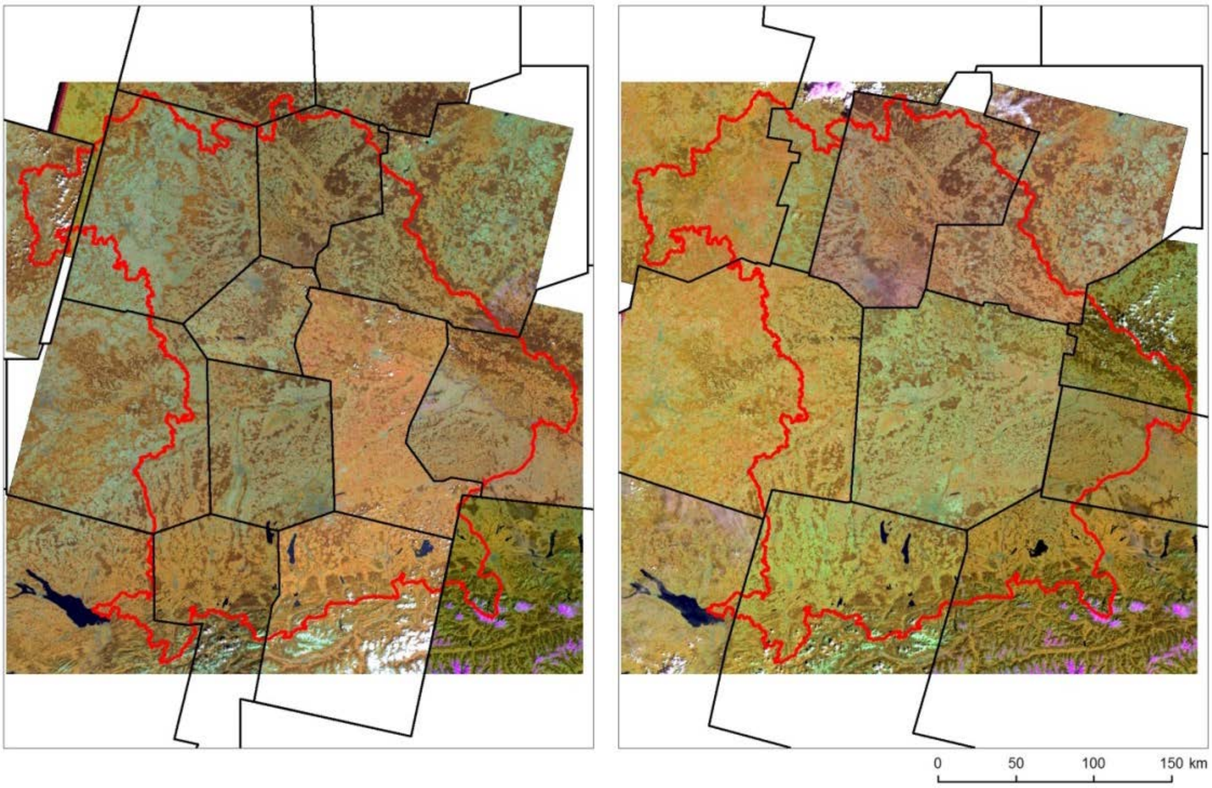
In order to simplify the processing, scenes as cloud-free as possible were chosen for the six macro-regions to get prepared from the two covers in the spring and summer, to create image mosaics in the projection of Gauss-Krueger zone 3. The mosaicking was performed with routines of the ERDAS Imagine software. By means of associated shape-files which documented the boundaries of the scene segments used, the incoming scene for each sub-area of the mosaic was documented. In a further step, the scenes were similarly assigned concerning the associated cloud masks by which also a mosaic for each macro-region was built. The cloud masks resulted from available interim results from the CATENA system; they included besides parameters for the cloud pixel values also parameters for cloud shadows and snow cover in the spring scenes. If necessary, the respective cloud mask mosaic was improved interactively by comparison with the image mosaic and by using optimized GIS routines.

In part, it was necessary in some macro-regions to use also SPOT data and sub-scenes of the Landsat data base besides the LISS-III data base to fill data gaps.

5.3.3 Mosaicking of Landsat summer data

Appropriate steps in mosaic composition were carried out as by the IMAGE2006 data to create the Landsat image mosaics and the associated cloud masks. Examples of LISS-III and Landsat mosaics with the superimposed boundary lines are shown for comparison in Figure 12 for the macro-region BY.

Figure 12: Example for the results of mosaicking of LISS-III and Landsat for Bavaria. The super-imposed border lines („seamlines“) mark the used sub-scenes of the corresponding satellite data. Left: Mosaic of LISS-III summer data (IMAGE 2006); right: mosaic of Landsat summer data. Sources: Satellite data © ANTRIX, Euromap / GAF AG (LISS-III), USGS/NASA (Landsat).



The derivation of cloud masks from the Landsat image data was done previously by an open source software, the software package Fmask (Function of mask). Fmask is based on an approach of Zhu & Woodcock (2012), the software was developed for data of Landsat sensors, which in addition to the reflective bands also include a thermal band with information on the areas with clouds, cloud shadows and snow cover. The code is created in the Matlab software, but the executables (for Windows and Linux systems) can be used also without Matlab installation and license (see Google Code, 2014).

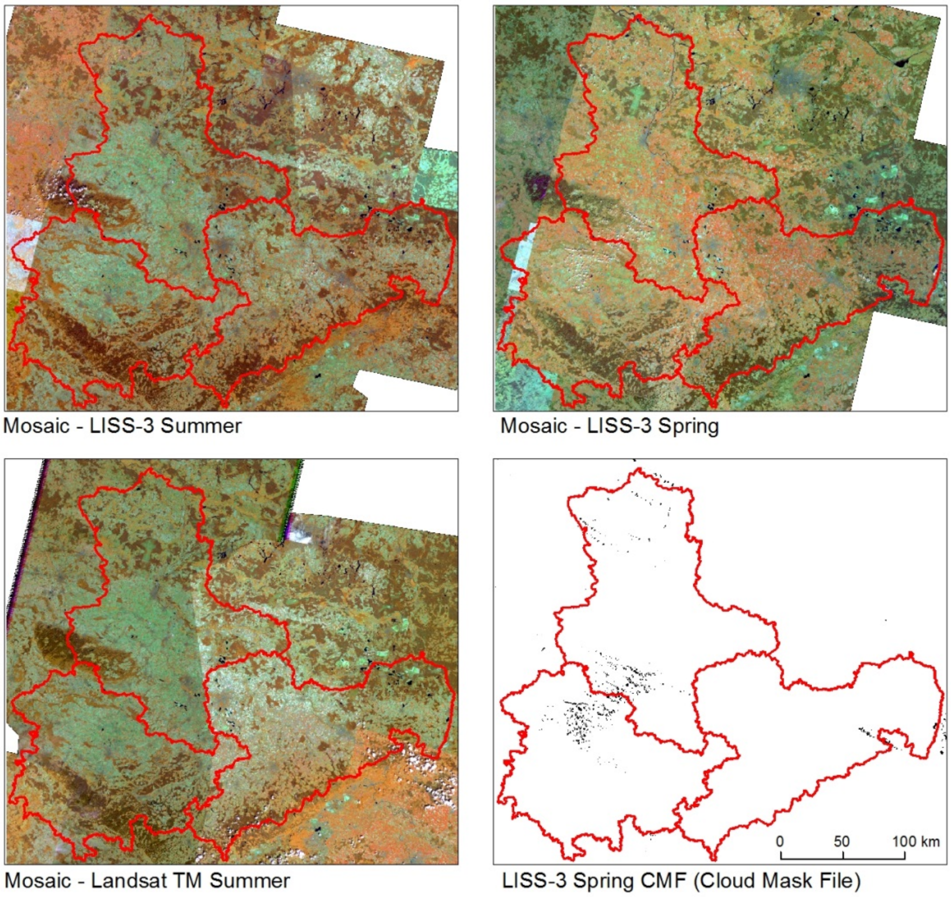
Table 10 contains a list reporting on the percentages of the cloud-related data gaps for each region and the three coverages of LISS-III spring, LISS-III summer and Landsat summer.

Table 10: Percentages of cloud and snow based data gaps for the six macro-regions, based on the derived cloud-masks.

	Cloud cover in %		
Macro-region	**LISS-III Spring**	**LISS-III Summer**	**Landsat 5 TM Sommer**
SH (SH,HB, NI, HH)	0,03	0,64	0,00
MV (MV, BE, BB)	0,65	0,34	0,69
ST (ST, SN, TH)	0,29	0,21	0,33
NW (NW, RP, SL, HE)	0,03	0,70	0,71
BW	3,80	3,10	0,00
BY	0,87	0,60	0,34

Figure 13 shows the three image mosaics and associated cloud mask layers (for spring) for the macro-region ST (Saxony-Anhalt, Saxony, Thuringia).

Figure 13: Coverage of the macro-region ST (Saxony, Thuringia, Saxony-Anhalt) by satellite data of IMAGE2006 (LISS-III) and Landsat TM. Sources: satellite data © ANTRIX, Euromap / GAF AG (LISS-III), USGS/NASA (Landsat).



5.3.4 Ortho-rectification of the IRS-P6 AWiFS data

For the geometric and radiometric pre-processing of the IRS-P6 AWiFS data, the operational system of the generic processing chain CATENA was available, conducted at the DLR institute of Applied Remote Sensing Technology (IMF). CATENA enables sensor-specific processing by using various meta data (Müller et al., 2012; Krauss et al, 2013).

The IRS-P6 data were supplied by the company EUROMAP as system-corrected data, in the status "orthokit ready", in path corrected data files in the map projection of "Lambert Conformal Conical" with the datum of WGS-84. The recorded orbit and attitude data of the satellite are integrated in a modeling of the satellite geometry that can be used for an ortho-rectification of AWiFS data by automatically detected control points and a digital terrain model. Thus the position geometry is significantly improved. As a geometric reference, the world-wide available ortho-rectified Landsat ETM + PAN image data base was used with a resolution of 0.45 arc seconds (approximately equivalent to 15 m pixel resolution).

In order to have the best possible adaptation compared to LISS-III data, the already ortho-rectified IMAGE2006 data base (the LISS III data of 2006) was utilized as a reference in the project. As a terrain model, the so-called global "best of" DEM was used, composed of a DEM based on the "Shuttle Radar Topographic Mission" with data of the SRTM X-band, the SRTM C-band and regionally available other DEM data to fill data gaps (Müller et al., 2007). The ortho-rectification was initially performed - due to the system - in the UTM coordinate system. Afterwards, the satellite products were transferred into the Gauss-Krueger projection, Zone 3, also applying the datum of DHDN as for the DLM-DE data. For resampling, a "cubic spline" was used for interpolation.

The radiometric preprocessing includes, among other things, a derivation of cloud pixels, cloud shadow pixels, pixels of the snow cover and water cover, based on the atmospheric correction program ATCOR (Richter, 2008). For this data, an atmospheric correction including terrain correction (using the module ATCOR-3) was carried out integrated in CATENA. ATCOR-3 was developed especially for radiometric corrections in illumination situations influenced by a strong relief (Richter et al, 2011), treating also DEM information. However, a review found that the terrain correction often led to overcorrection with accompanying artifacts. Therefore, the AWiFS data were used only in the geometrically corrected form and not as preprocessed by ATCOR-3 radiometrically corrected products. For the planned future use of spectral indices for the time series (with derivation of ratios), it was to be expected that effects of terrain illumination were mostly compensated.

5.3.5 Creation of multi-seasonal AWiFS mosaics

In analogy to the image mosaics of IMAGE2006 and Landsat data, also the AWiFS data fitting to the respective record period were composed to image mosaics. An additional 0-1 mask created per month showed, whether valid AWiFS data were available, or if data gaps were present due to missing scene coverage or as a result of clouds or cloud shadows.

Figure 14 shows an example of an image sequence of AWiFS mosaics for macro-region BY (Bavaria). For the most parts of Bavaria, 6 to 7 scene coverages were available, apart from small cloud gaps.

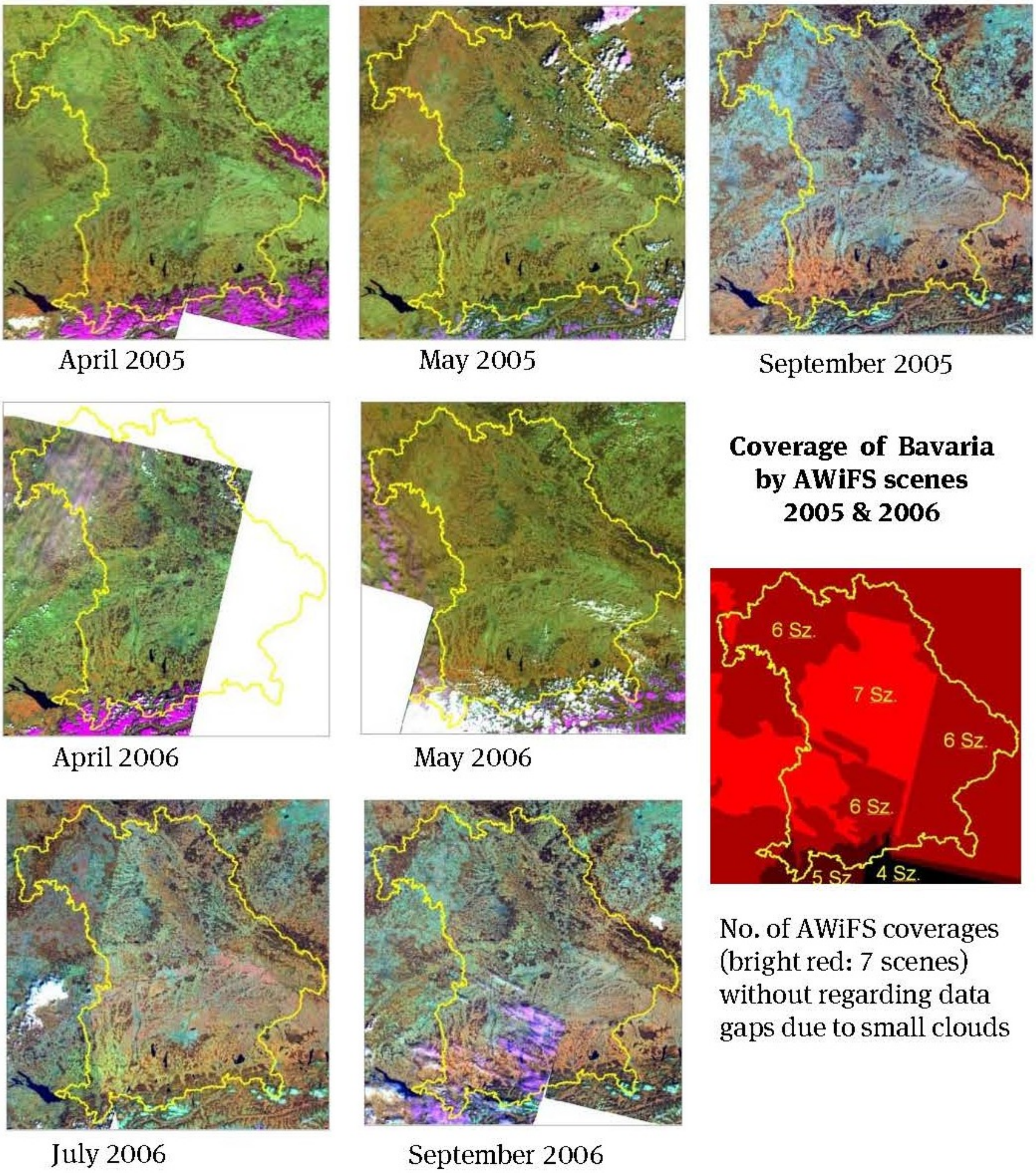
5.3.6 Deduction of temporal statistics of the AWiFS NDVI time series

Building on the mosaicked AWiFS images, the vegetation index NDVI („Normalized Difference Vegetation Index“; see e.g. Rouse et al., 1973) was calculated for all record months. The NDVI is defined as combination of the bands of near infrared and visible red (see Table 4):

- NDVI = (NIR – VIS-R) / (NIR + VIS-R).

The temporal sequence and dynamics of the NDVI values per pixel element contain characteristic information describing the way of agricultural use, especially concerning the distinction of arable land and grassland. In original, the NDVI would have values in the range between -1 and +1 due to the formula. For presentation purposes, the NDVI values were normalized to the positive interval between 0 and 200.

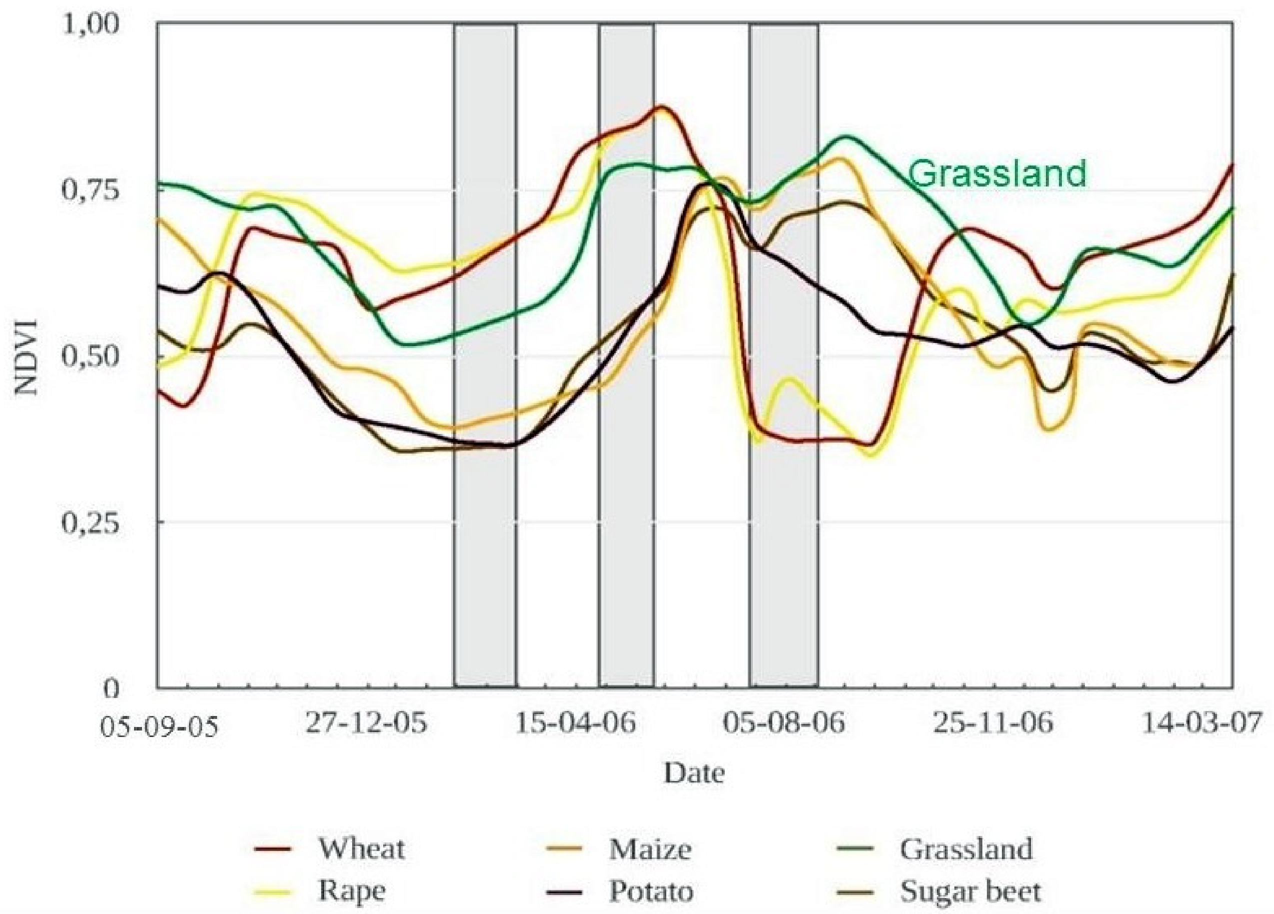
Figure 14: Coverage of Bavaria by multi-seasonal AWiFS data. © ANTRIX, Euromap / GAF AG.



A successful use of multi-seasonal and multi-sensoral satellite data for vegetation mapping has already been demonstrated in Germany in various projects, as described in Itzerott & Kaden (2006), Goessl et al. (2010) and Feilhauer et al. (2012).

In the framework of the parallel studies to CLC2006 (Metz, 2009; Keil et al, 2010c), temporal NDVI signatures of the MODIS sensor have been studied in agricultural study areas of Mecklenburg-Western Pomerania. MODIS delivers daily records, but only with a spatial resolution of 250 m by 250 m. Several crop types as well as grassland were included. MODIS based NDVI curves describe the phenology of the various vegetation types, and by these curves, information on important periods for the differentiation of grassland and various crops can be derived. Thus, the late July and the August period are well suited for the separation of cereals and grassland; in April, maize and grassland can be well separated. This time window is also important for NDVI time series of AWiFS. An example from Mecklenburg is shown in Figure 15.

Figure 15: Average phenology curves for wheat, rape, maize, potatoes, sugar beets and grassland showing potential intervals for a separation of cropland and grassland (grey intervals), based on derived MODIS NDVI values. Source: Metz, 2009, modified.



Since the temporal coverage with AWiFS data was different concerning the regions of Germany and also comparing the years 2005 and 2006, it was necessary to choose as robust as possible indicators to characterize the different dynamics of arable land and grassland. Generally, it can be assumed that the temporal NDVI changes of grassland towards the cycles are lower in arable land, although larger variations are to be expected as a result of grass clippings. Also, the average NDVI level of grassland (over the period from March / April to September / October) should tend to be higher than that of the various main crops on arable land. A third criterion could be the position of the NDVI minimum.

For the characterization of the time series, five statistical parameters were determined which remain valid also over a period of two years, concerning the distinction of arable land and grassland. These parameters are:

- Minimum,
- Maximum,
- Mean,
- Standard deviation,
- Range.

Together with a sixth parameter which specifies the number of valid NDVI values, these layers were combined in a multi-band temporal statistics record. A graph illustrating the temporal statistical parameters can be found in Figure 16.

Figure 16: Input data and thematic products deduced from temporal statistics for the example of the macro-region NW (North Rhine-Westphalia, Rhineland-Palatinate, Saarland, Hesse). The temporal statistics data were created from the time series of monthly NDVI mosaics of AWiFS satellite data from the years 2005 and 2006. The temporal statistics data set consists of six individual thematic layers: minimum, maximum, mean, standard deviation, range as well as the number of valid NDVI scenes. Sources: satellite data © ANTRIX, Euromap / GAF AG (AWiFS).

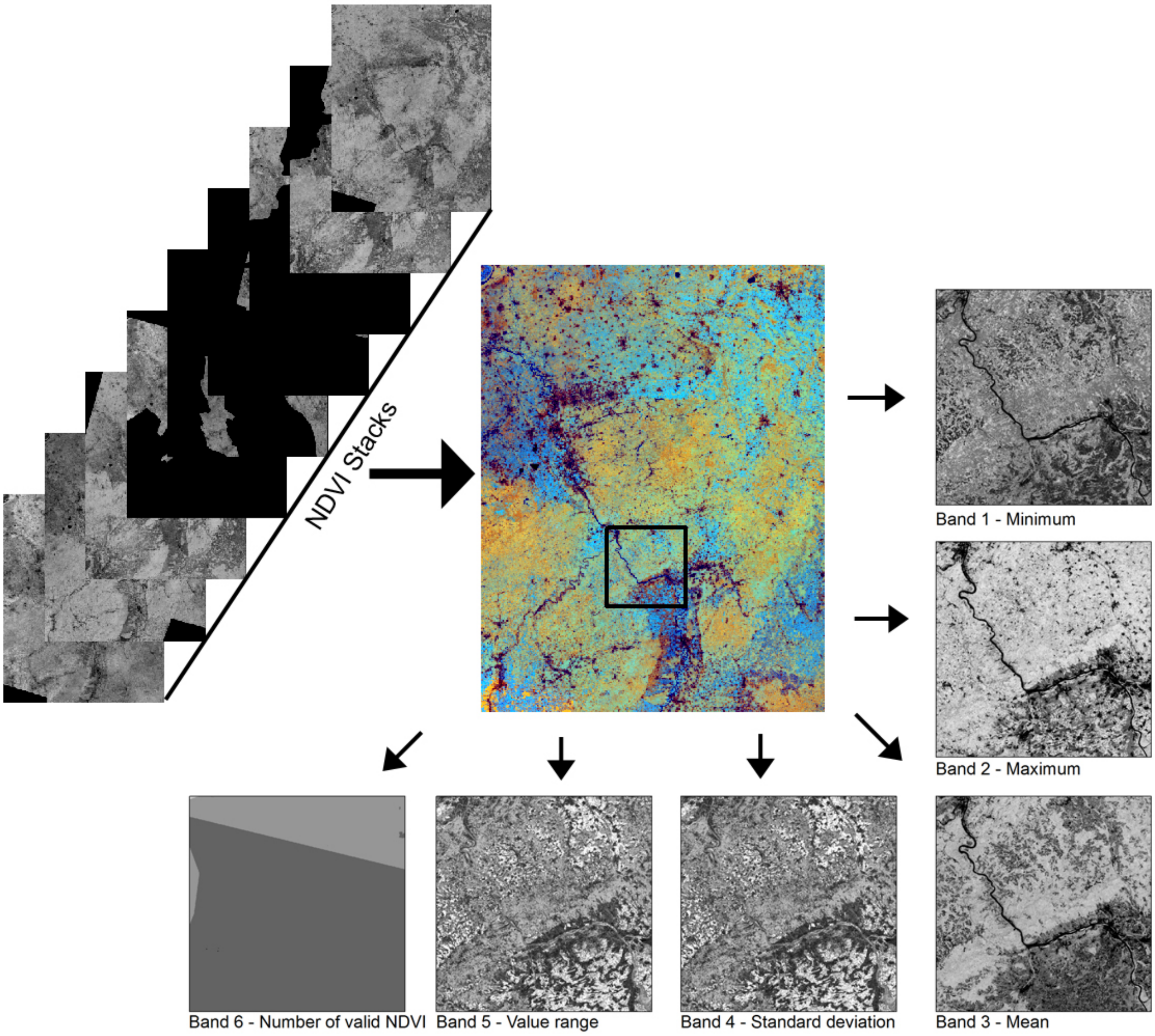
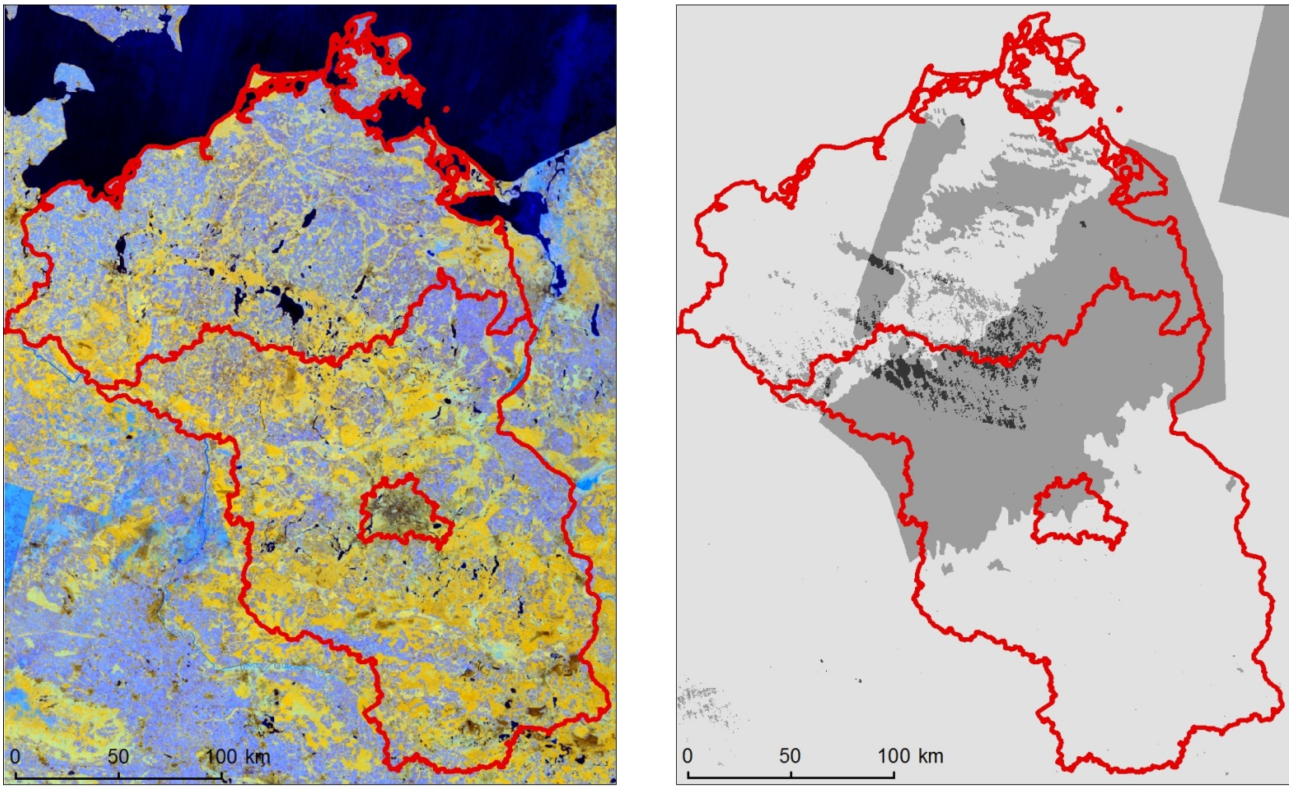


Figure 17 shows the result for the macro-region MV, in the band combination 1, 3, 4 (minimum, mean, standard deviation) in RGB presentation which was mostly used.

The dominant arable areas in Mecklenburg-Western Pomerania are clearly visible in blue tones, they display a high standard deviation representing the dominant band here (set to blue); they are traversed by grassland sites in yellowish tones in the glacial valleys. The forest areas North and South of Berlin show dark yellow to brownish tones. The number of available cloud-free NDVI pixels decrease to the value 4 in the Northwest of Brandenburg, a result of partial cloud cover; but over large areas, 5 to 6 valid pixels are included in the temporal statistics.

Figure 17: Representation of temporal statistics of AWiFS NDVI time series using the example of the macro-region MV. Left: combination of three statistical parameters; right: number of available cloud-free covers. © ANTRIX, Euromap / GAF AG (AWiFS).



Temporal statistics of AWiFS NDVI time series

Band combination: band 1-3-4 (RGB), with
Band 1 - Minimum
Band 3 - Mean
Band 4 - Standard deviation

Number of available
cloud-free coverages

4
5
6

5.4 Deduction of thematic interim layers

5.4.1 Preparation of the soil sealing layers 2006

As mentioned, the layer of soil sealing is available in two versions, on the one hand as “EEA Fast Track Service Precursor on Land Monitoring – Degree of soil sealing” (EEA, 2010), including also mineral extraction sites and construction sites, on the other hand in a second improved version, as “Revised Soil Sealing 2006, degrees of sealing 20 m and 100 m”. In this second version, mineral extraction sites and partly construction sites are not included. Pre-studies showed that a derived layer for built-up areas, e.g. by using a threshold of >= 70% degree of soil sealing, delivered no advantage in relation to the built-up mask from the Basis-DLM. As additional layer, however, the layer of soil sealing gave support in situations in which a small part was sealed in already defined industrial and commercial areas, but with a bigger sealed part in 2009, indicating changes. Furthermore, the two variants of the sealing layer were included in the derivation of mining areas and construction sites.

5.4.2 Preparation of the “ATKIS Basis-DLM Flat Layer 2006 “

The ATKIS Basis-DLM flat layer 2006, also called BDLM_flat 2006, existed already, separate for the federal states in the form of polygon shapefile. Only those polygons were included in the direct processing, which described the built-up areas and forest distribution in 2006. The other polygons were regarded only for comparison purposes and as an additional layer in the steps of manual improving of the change layer, taking into account that the status shown could possibly no longer be the current one.

5.4.3 Layer Built-up 2006 from the Basis-DLM 2006

The built-up layer in the individual federal states were formed from the BDLM_flat 2006 polygons which included in the potential CLC classes (according to attribute CLC_BKG) at least one of the CLC categories 111,112 or 121, or combinations of them with other classes. The CLC class 122 (road and rail network) was not included in BDLM_flat 2006, as the corresponding categories originally existed in ATKIS as polylines with additional attributes specifying their widths. The build-up layer, also called "urban mask", was used as an exclusion area regarding arable land / grassland separation in agricultural land.

5.4.4 Layer Forest Cover 2006 from the Basis-DLM 2006

Another mask layer was derived from BDLM_flat 2006, the forest mask to the state of 2006. For defining this mask, all polygons were used, which at least contained one of the CLC categories 311, 312, 313 or 324 in the attribute CLC_BKG, partly also in combination with other potential classes. The forest mask was also used as an exclusion area in terms of agricultural land in cropland / grassland separation, and as well as additional information in the derivation of changes concerning forest classes.

5.5 Deduction of thematic raster layers

5.5.1 Water mask (CLC 512)

The water mask, containing in principle the CLC classes 511 and 512, is interesting in relation to the change classes for the four transitions 131 -> 512, 211 -> 512, 231 -> 512 and 333- > 512, according to the Table 8 and Table 9, all of them presenting transitions into the status of 512 (of water) in 2009. In the status 2006, the water mask is of interest, as it has to be checked if a water body exists already in 2006, or if the area still presents an extraction site 131 or a succession state 333 on former mining areas (before flooding). The water mask is also incorporated as an exclusion area in the classification of arable land and grassland. In the contributions to be checked in the areas of potential change areas of DLM-DE2009, the CLC class 512 does not matter.

Information about the delimitation of water areas can be found in various indices, such as in the vegetation index NDVI

- NDVI = (NIR – VIS-R) / (NIR + VIS-R),

but also in various „water indices“ or „wetness indices“.

Here the "Modified Normalized Difference Water Index" (MNDWI) by Xu (2006) has been selected. This index is defined as a combination of visible green band (VIS-G) and the short-wave infrared band (SWIR), for Landsat TM the bands 2 and 5:

- MNDWI (Xu) = (VIS-G - SWIR) / (VIS-G + SWIR).

Indices have the advantage that they can simply be used in a thresholding approach for separating "water" and "non-water" areas.

Another indicator for the delimitation of water areas is the SWIR band itself (e.g. band 5 for Landsat). But the SWIR itself is not put in relation to a denominator (as ratio). This implies that different acquisition and illumination situations need to be considered for direct use of the SWIR band for thresholding of water surfaces. This was done by dividing the mosaics into the strips of records at the same time, using the "seamlines" (the border lines) of the scenes. For thresholding by the Landsat SWIR band in the federal state of Baden-Württemberg, it was sufficient to perform a division into a Western part and an Eastern part. By that, separate thresholds were determined, and later the extracted products in the sub-regions were combined again to include all water bodies. Other macro-regions required a bigger sub-division.

To derive the water mask, all three individual masks were used. Using thresholds it was tried to cover all areas of water completely, initially with the acceptance of overestimation. The final water mask was then determined by intersection of the three individual masks. This methodology had the advantage that the mixed pixels near the shores could be better integrated in the determination of water bodies. But an interactive correction step had still to be connected by later extinction or additional introduction of water pixels, which took place in ArcGIS by utilizing specific Python scripts.

A plot of the water mask determination is shown in Figure 18.

5.5.2 Mineral extraction sites (CLC 131)

The mineral extraction sites (CLC class 131) in 2006 were determined by a rather complex set of rules using the two versions of soil sealing layer 2006, the database DLM-DE2009, CLC2006 (25ha) and the individual Landsat layers 2006 in GK3 coordinates. The processing was carried out mainly in ERDAS Imagine, the "ERDAS Graphic Modeler" was used for modeling.

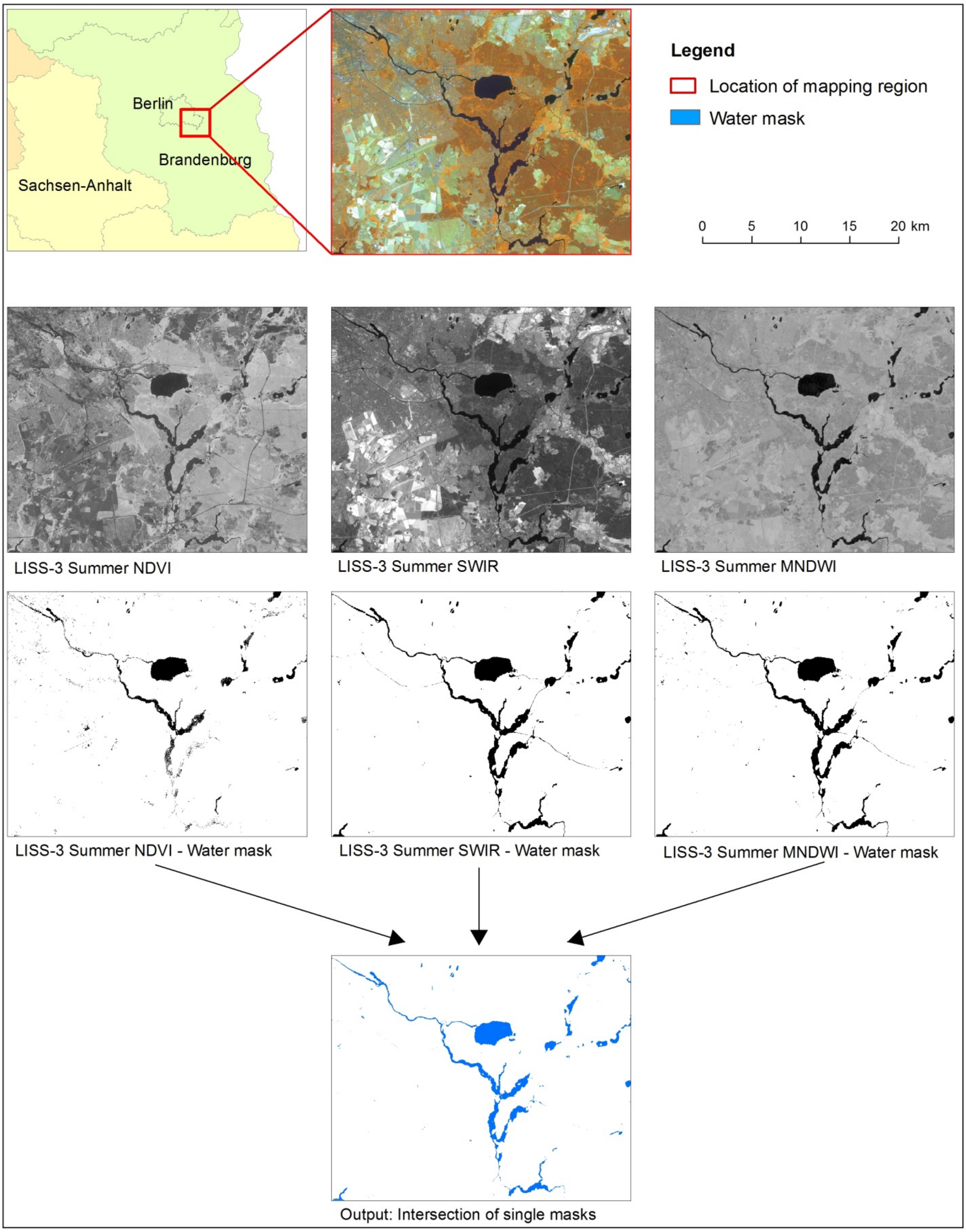
The following conditions had to be met for an assignment to 131:

- For a definition of built-up and mineral extraction mask from the soil sealing layer (version 1), areas were included from 80% degree of soil sealing upwards.
- The mineral extraction sites had to be part of the mask resulting from subtracting the build-up masks with and without mineral extraction and construction sites (from 80% degree of soil sealing upwards).
- The potential extraction sites had to show a plausible further development state in 2009 - that meant to belong either to the class 131, or to a potential renaturation or recultivation state, i.e. to one of the categories 131, 132, 331, 333, 321, 231, 211, 324, or 512 in DLM-DE2009.
- In order to better integrate diverse states of brown coal mining (not all showing the high degrees of sealing in the product "Soil Sealing Version 1"), the coarse boundaries of 131 in CLC2006 (25 ha MMU) were also integrated to the mining areas, but under exclusion of areas with a higher proportion of vegetation and of water coverage (using NDVI and a water index, derived in the original ortho-rectified Landsat-products).
- The individual mining masks (0-1 masks) from the individual Landsat scenes were superimposed later for a total coverage of macro-regions, and then combined with the mineral extraction mask derived from the two soil sealing products.

5.5.3 Construction sites (CLC 133)

The construction sites (CLC category 133) were similarly derived from the difference of "Soil Sealing Layer 2006" with and without inclusion of mining and construction sites. As a rule, the additional condition had been established that the state of the DLM-DE2009 was defined as class 133, or one of the urban classes 111, 112, 121, or 122. The additional processing of Landsat scenes was not necessary. In addition, however, the polygons of the CLC Change Layer (2000 to 2006) showing class 133 in 2006 were also included (with the minimum mapping unit of 5 ha).

Figure 18: Presentation of the water mask 2006 derivation, based on three synthetic indicator bands, deduced from IRS-P6 LISS-III data. The region of the example is situated in the SE of Berlin. Sources: satellite data © ANTRIX, Euromap / GAF AG (LISS-III).



5.5.4 Arable areas (CLC 211)

As already explained in chapter 5.3.6, parameters of the temporal statistics of AWiFS based NDVI time series were used to delineate areas of arable land and grassland. The delineation from other land cover classes was done by an inclusion of three thematic interim layers at the status 2006, the urban mask, the forest mask and the water mask.

After various tests, three statistic parameters were used for defining the rules for the arable land / grassland separation, the bands of "minimum", "mean" and "standard deviation" of the temporal distribution of NDVI pixel values.

By using again specific thresholds for these bands, three individual masks were derived for potential arable areas, first (as for the water masks) each showing overestimations of arable land. But then an intersection of these three masks followed, defining the mask of arable land (as 0-1-mask).

5.5.5 Grassland areas (CLC 231)

The three statistics parameter bands "minimum", "average" and " standard deviation" were used according to the temporal NDVI distribution also for the derivation of the grassland mask. First, again suitable thresholds were chosen for the individual masks, which then were combined by an intersection of the single masks for generating the grassland mask.

An example of the selected threshold values for the separation of arable land and grassland (here for the macro-region NW) is shown in Table 11.

To cover agricultural areas as much as possible by the arable and grassland masks, the thresholds for both categories were designed relatively far. Therefore, the masks of grassland areas covered also large parts of the forest areas, but these parts were eliminated by the forest mask derived from Basis-DLM_2006. Some areas remained being eligible for both arable land and grassland, according to the relevant rules. In the rule sets for these areas, priority was given to arable land, based on various test runs. In addition, the permanent crop areas due to the CLC category 222 in CLC2006 (25 ha MMU) were excluded because their statistics were quite similar to the grassland statistics.

The optimization of the threshold values in several test runs was performed separately for each macro-region, with the already acquired knowledge from the previous regions. It can be assumed that the temporal NDVI dynamics of arable land and grasslands, e.g. concerning the range of variation in different landscapes, can turn out quite differently (e.g. in lowlands in comparison to mountain ranges). Compared to the use of points in time for the "start of greening" or "yellow ripeness" of certain crops that can also be used for crop identification by using phenological standard curves (only after several adjustment steps; Itzerott & Kaden, 2006), statistical parameters such as minimum, mean and standard deviation are more robust indicators. The spatial variations were to be regarded in a subsequent check and improvement step of automatically defined change areas between arable land and grassland.

Table 11: Rule sets with the applied thresholds for the delineation of arable land (CLC class 211) and grass land (CLC class 231)

CLC category	Statistic parameter	Rule for single mask
211	Minimum	<= 144
	Mean	<= 161
	Standard deviation	>= 8
231	Minimum	> 138
	Mean	>= 150
	Standard deviation	<= 4

5.5.6 Forest distribution concerning the forest classes (CLC 311, 312, 313, 324)

Due to CORINE Land Cover nomenclature, forested areas can be characterized by the following four CLC classes:

- Deciduous forest (311),
- Coniferous forest (312),
- Mixed deciduous coniferous forest (313),
- Woodland-shrub transition (324).

Not regarded are the wooded areas within urban green areas (CLC-Class 141) in the context of communities which are not considered for possible change processes.

For the definition of forest areas, the forest mask derived from the ATKIS Basis-DLM (Flat Layer) can be used as a satisfactory basis with respect to its timeliness, in order to distinguish these areas against agricultural land, built-up areas and other land cover categories. But for the inner structure in terms of forest classes, a derivation by means of satellite image information is required for the reference year 2006.

Regarding the change processes connected with forest growth, i.e. the transition of 324 to the classes 31x (311, 312 , 313), the starting position 2006 was created by combining the CLC classes (25 ha MMU) with refined information from the change Layer CLC_Change (2000 to 2006, with 5 ha MMU), formed with respect to the distribution of 324 in 2006.

The other main change process in terms of internal forest class changes is the process of storm damage and / or clearing, followed by afforestation. Typical situations during storm damages are still existing distributions of old stocks of 311, 312 and 313 in 2006, which are damaged and partly transferred to woodland-shrub transition (324) up to 2009, with remaining old stands in the neighborhood. An automatic detection of changes from 2006 to 2009 is primarily possible only for the transition 312 -> 324 (as result of storm damage), because in mixed forests the distinction to forest - shrub transition stages is quite complicating. Due to the change layers between 2000 and 2006, the change areas connected with transition 312 -> 324 reach an approximately 10-fold value compared with the areas of transition 313 - > 324, and an approximately 30-fold value, compared with the areas of transition 311- > 324. Thus, a focusing on the changes from 312 to 324 appears to be reasonable for this type of changes. During storm damages, the shallow-rooted spruce stands (part of class 312) are often affected as the first stands. A lot of changes in forests between 2006 and 2009 were induced by the hurricane Cyril which raged on the dates of 18 and 19 January 2007. By this hurricane, particularly forests in North Rhine - Westphalia (especially in the Sauerland region) and in Northern Hesse were heavily affected; again, dominantly spruce stands.

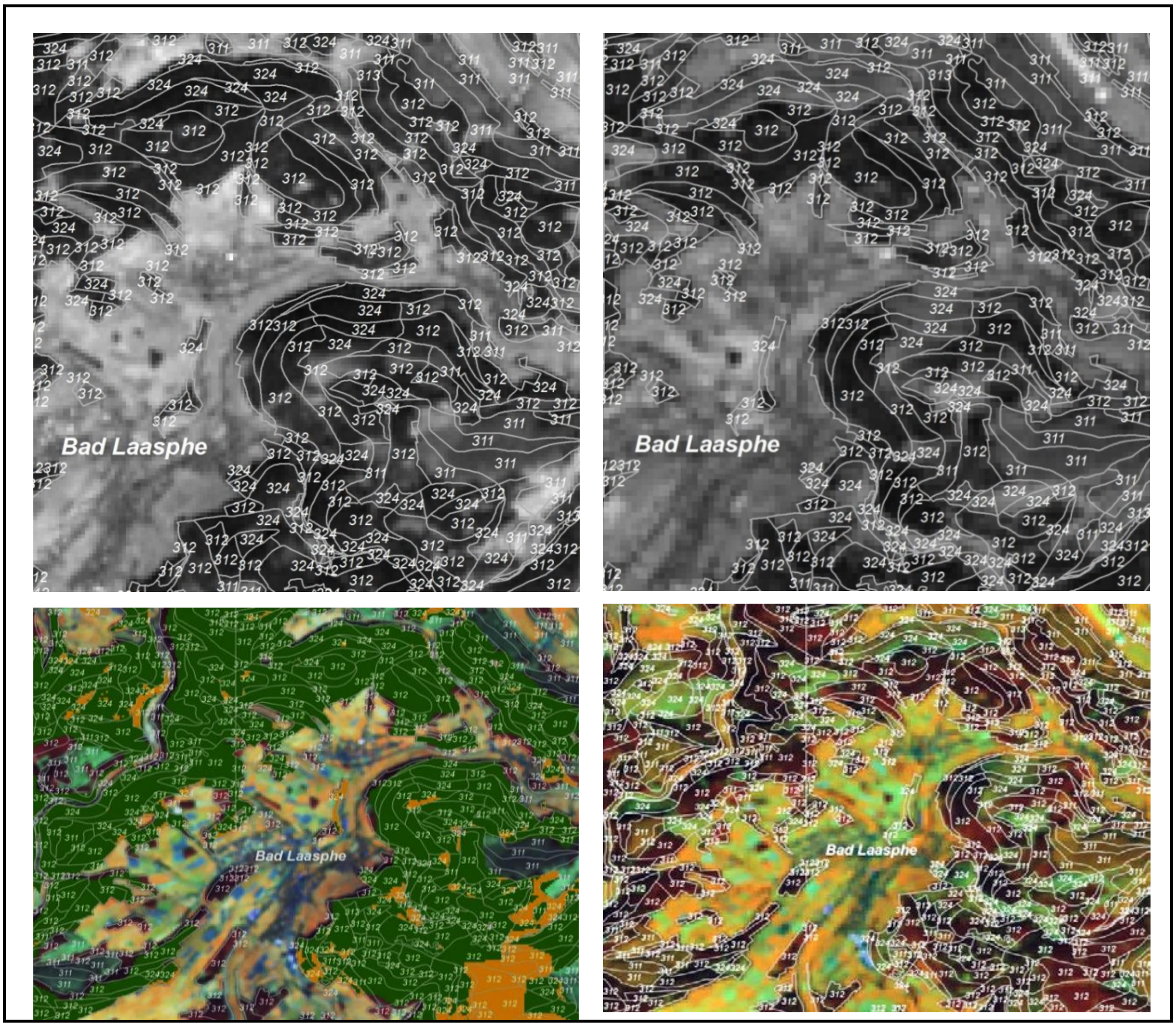
Concerning the forest change areas resulting for class 324 in 2009, the primary task is to derive the fine structure of (still) class 312 and (already) 324 in the stands of 2006, which means to delineate the changes 312->324 from already existing woodland-shrub transition states (class 324) in 2006.

Due to a number of studies, the SWIR band (" Short Wave Infrared") in the LISS-III or Landsat summer mosaics has been shown to be very sensitive for the definition of stable old coniferous forest parts against woodland-shrub transition. Therefore, the forest distribution status in 2006 was derived for the forest parts, attributed to classes 324 and 312 in the DLM-DE 2009. Thresholding was used based on the SWIR band. However, a split of the mosaic was again necessary due to the alternating recording dates. This allowed it to determine separate thresholds for the mosaic sub-scenes.

As an example, Figure 19 shows the delineation of intact coniferous forest stands (312) and woodland-shrub transition states (324) in the Sauerland region, macro-region NW, which were probably affected by storm damages induced by Cyril.

For the generation of the thematic forest layer, it was finally necessary to match the refined distributions of classes 312 and 324 with the other intermediate products of class 311 and 313 distributions (with 25 ha to 5 ha MMU), and to produce also for these forest classes corresponding intersections and refined thematic raster layers.

Figure 19: Assessment of a coniferous forest affected by storm damages, with intact stands (312, green) and transitional woodland-shrub patterns (324, orange) for 2006 (l. r.), by use of SWIR band of LISS-III spring 2006 (u. l.). – For comparison, a Landsat scene of summer 2009 is shown by the SWIR band (u. r.) and in a composite of bands 4,5,3 (l. r., in RGB); overlay: DLM-DE2009 for forest areas. Region: Sauerland, North Rhine-Westfalia. Change areas (due to storm damages) occur especially on the Northern edge of the image. Sources: Satellite data © ANTRIX, Euromap / GAF AG (LISS-III); geobasis data © German Federal Agency for Cartography and Geodesy (www.bkg.bund.de).



5.5.7 Only regional distributed land cover classes (CLC 222, 321, 331, 333)

In the most common 46 changes based on the period 2000 to 2006 (see Sect. 3.2), some land cover classes play a special role, as their occurrence is more regionally, and it is difficult to distinguish them from other CLC classes by automated methods. The corresponding transitions start from the following CLC classes:

- Permanent crops with fruit trees and berry plantations (222),
- Beaches, dunes and sand (331),
- Sparsely vegetated areas (333),
- Natural grassland (321).

Often, permanent crops of fruit cultivations (222) are common in climate favored base positions of low mountains. Beaches, dunes and sand flats (331) occur primarily in the coastal area of the North Sea. The areas with sparse vegetation (333) are often connected with the restoration of abandoned mining areas or with respect to successional stages on a former military training area.

In order to integrate at least large areas of these categories with potential change in the polygons, the corresponding polygons of CLC2006 (25 ha MMU) were directly converted into thematic raster layers, in the form of 0-1 masks. These four thematic layers thus have a similar importance as the other eight thematic raster layers, which were created on the basis of higher resolution satellite-based products as 0-1 masks as well: that are the mineral extraction sites (131), the construction sites (133), the arable (211) and grassland (231) areas and the four woodland layers (311, 312 , 313, 324).

5.6 Integration of the information from DLM-DE 2009, the satellite data from 2006 and the deduced thematic information layers

By generating the 12 thematic raster layer, which carry the thematic information for 2006 and correspond to one of the CLC-Classes (see previous chapter), the classes of 2006 participating in the main changes are determined, and their spatial distribution in 2006 is characterized. In order to model the backdating datasets, the following tasks remain:

- Identification of potentially change affected polygons in the structure of the geometry of DLM-DE 2009,
- Determining of polygons which show entirely (or in dominance) a transition to another CLC-Class between 2006 and 2009,
- Subdivision of polygons that are affected by change in some areas, supported by segmentation methods and by using appropriate high-resolution satellite data,
- Assignment of the respective dominant CLC class, according to the thematic raster layers identified for the determined sub-segments.

The work flow with the corresponding data flow is shown as a summary graph in Figure 20, the processing steps are explained below.

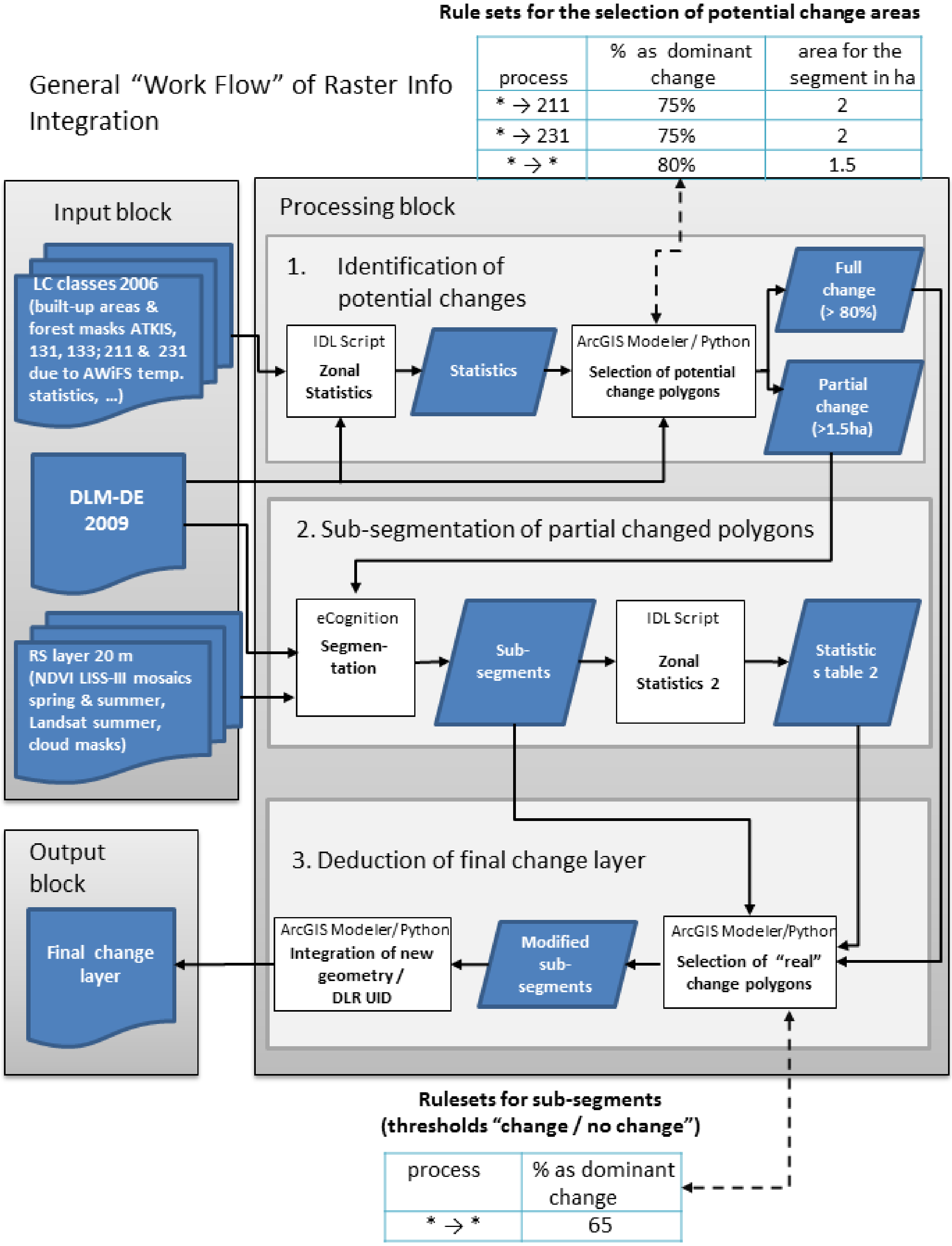
5.6.1 Identification of DLM-DE 2009 polygons with potential changes

Regarding the large number of polygons in DLM-DE 2009 and in order to ensure an appropriate processing time, it was shown that the pre-selection of potentially change affected polygons is essential for the step of segmentation. For macro-regions with a large number of polygons, also a division into two or three sub-units is required instead of the working unit of the whole macro-region.

For an unambiguous identification of polygons in the input data set of DLM-DE 2009, an additional attribute was introduced, the "DLR User ID", referred to as "DLR_UID". This DLR_UID was to make it possible to allow a tracing of the original polygons also in the case of sub-divided polygon. The DLR_UID was introduced as ("unsigned") 32-bit variable, first starting in the input polygons with a consecutive number, but multiplied by the value 100. Thus, theoretically 99 subdivisions were allowed per input polygon, which then were incremented in each sub-segment by one instead of keeping “smooth hundred” values.

For the pre-selection of these polygons, the corresponding percentage of the CLC classes regarding the twelve thematic raster layers has to be determined (hereinafter referred to as "thematic information layer"), in comparison to the CLC class of 2009. For the calculation of the "zonal statistics", a combination of methods was selected, which first converted the DLM-DE2009 subsets into raster data in exactly the same subsets in which the thematic layers were arranged. As pixel value for the corresponding thematic information subsets, the DLR_UID was used. The conversion to raster data was performed using ArcGIS.

Figure 20: Workflow during the integration of satellite image data, thematic raster layers and the input data of DLM-DE 2009 vector database.



For the determination of the zonal statistics, an IDL script was created with the input of the rasterized DLM-DE 2009 subsets and the DLR_UID as pixel value, with the 12 thematic information layers (0-1 as masks) present as well as raster data. The output of the zonal statistics was produced as a table in dbf format.

In order to mark the polygons with potential changes, a Python script integrated in ArcGIS was used for the analysis of this table. The selected polygons were divided into two groups with regard to the characters of modifications (see Figure 20):

- into change polygons with dominant change, in which the geometry is preserved; in this case, a new CLC class dominates by at least an 80 % area fraction (75% for agricultural classes),
- and into potential change polygons with partial changes (with new portions from 1.5 ha upward), in which a sub-division of the polygons for the various contributions is necessary.

This first part of processing, the polygon selection, is followed by the segmentation.

5.6.2 Segmentation / sub-segmentation of the affected DLM-DE 2009 polygons

The used segmentation software eCognition offers the possibility of defining multiple hierarchies of segmentations at different levels of resolution ("multi-resolution segmentation"; Esch et al., 2008), and also of sub-dividing an existing first base level of segments (e.g. after importation of polygon shapefiles) by linking this level with corresponding raster layers. This option was used in the project to match the selected DLM-DE2009 polygons with the available satellite based information at 20 m resolution.

For each macro-region, three mosaics were available:

- a mosaic describing the summer aspect by LISS-III data with clouds masks,
- a mosaic describing the spring aspect by LISS-III data with clouds masks,
- a mosaic describing the summer aspect by Landsat data with clouds masks.

After several preliminary studies, a set of rules was chosen that was based in each case in a special hierarchy on derived NDVI values in summer and in spring aspect to distinguish spectrally different units of land cover:

- First step: Integration of the polygons of DLM-DE 2009 potentially affected by changes, for producing segment level 1,
- second step: sub-segmentation of the segment level 1 by using NDVI LISS-III summer data, producing segment level 2, keeping the information on data gaps by cloud mask 1,
- third step: sub-segmentation of the segment level 2 by using NDVI LISS-III spring data, producing segment level 3, keeping the information on data gaps by cloud mask 2,
- forth step: sub-segmentation of the areas of data gaps from cloud masks 1 and 2, by using NDVI Landsat summer data producing segment level 4,
- fifth step: export of the sub-segments in Shape format.

Thus, the sub-segments are based on the IMAGE2006 data and the Landsat data in the mosaics, but the thematic information has still to be integrated in these sub-segments, again on the basis of the 12 thematic information layers.

A second time, the determination of the zonal statistics (in form of IDL-scripts) is used, again by assessing the units of sub-segments previously converted into raster data. The areas of the sub-segments are characterized by their new DLR_UID generated by incrementing the original DLR_UID in steps of 1 (see section 5.6.1).

5.6.3 Analysis of zonal statistics for class contribution and output of the change polygons

Using the Python script (in ArcGIS), the statistics table 2 is now accessed containing the units of the sub-segmentation. For each unit, a decision is made by the use of majority criteria whether a change polygon exists and to which CLC class for the year 2006 it belongs. With regard to the sub-segments, a threshold of 65% was taken as a criterion for a real change. The corresponding CLC class was added in an attribute CLC_ST06.

For those sub-areas that are not assigned to any real change after the sub-division of potential change polygons, the status in the attribute CLC_ST06 is set to "0". Also for this unit, a unique attribute DLR_UID is provided. The reason is that also these units are included later in the CLC2006_Backdating product, together with the derived partial change units.

The new parts of the affected polygons derived from the mosaic data show step-wise outlines in the beginning. But smoothing algorithms in ArcGIS are used, which are oriented at the geometries of the neighboring original polyline parts. This leads mostly to the fact that the original pixel boundaries can be recognized only in the new lines which were generated by the segmentation (see Figure 21).

An example of change detection with the original potential change polygons and the final results are shown in Figure 22.

Figure 21: Inclusion of the thematic information layer into the derived sub-segments and resulting smoothed polygons of the change layer. Geobasis data © German Federal Agency for Cartography and Geodesy (www.bkg.bund.de).

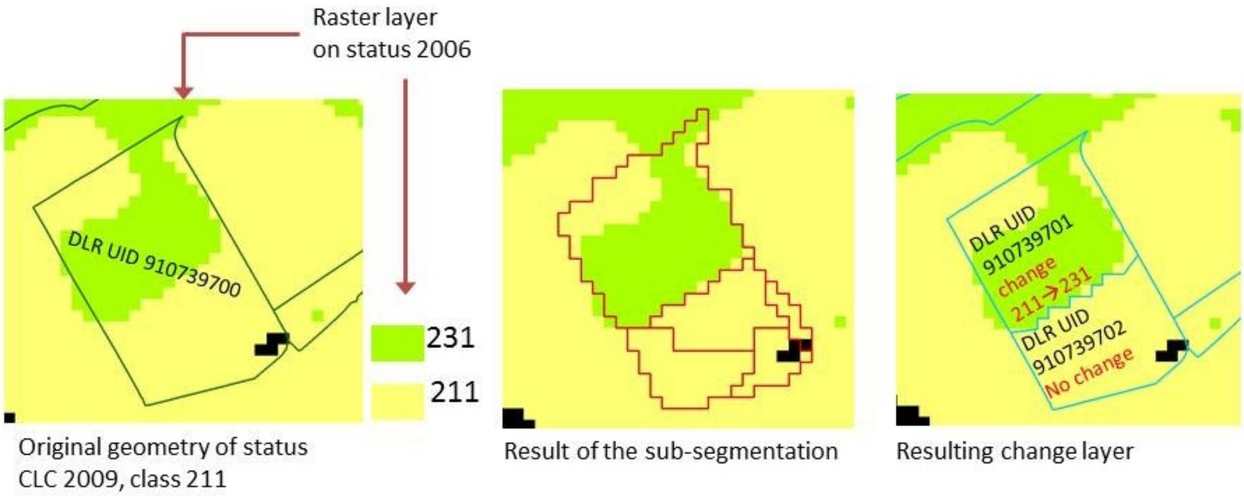
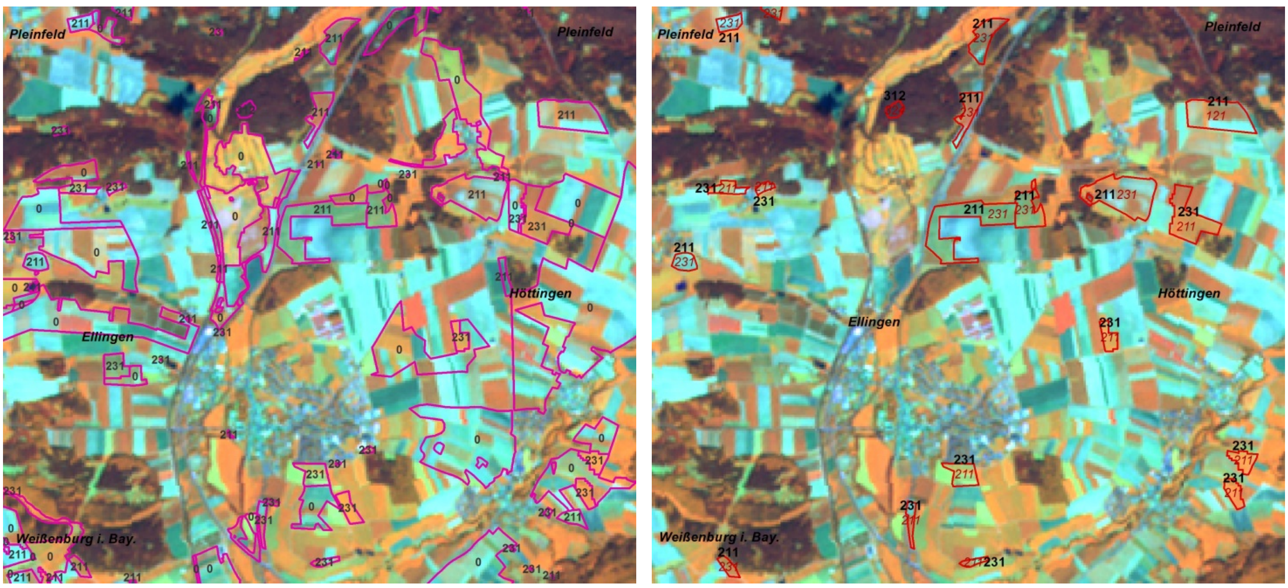


Figure 22: Example of a result of change detection - to the left including parts of potential change areas without change (CLC_ST06 = 0), to the right the result (in black: status in 2006; in red and italic: status in 2009). Background: LISS-III summer scene. Sources: Satellite data © ANTRIX, Euromap / GAF AG (LISS-III). Geobasis data © German Federal Agency for Cartography and Geodesy (www.bkg.bund.de).



5.7 Plausibility checks and improvement of the change polygons

The automatic processing for delineation of change polygons leads to a change layer, which also contains the associated polygon parts not changed in relation to DLM-DE2009. These parts are often larger than the actual change areas. In addition, a lot of small polygons under 1 ha occur, which are partly caused by small differences between the derived forest and built-up mask in 2006 to the corresponding units in 2009. For example, the Basis-DLM_flat 2006 includes no roads and railway lines in form of polygons. These objects are included in ATKIS as polylines. Often, longer linear objects exist, which accompany the "gaps" of roads and are assigned as roadside vegetation to the CLC classes 231 or 324 in 2009. This made it necessary before further plausibility checks of the polygons to review these in terms of their aerial size and to mark them accordingly.

Alltogether, the strategy was pursued for the checks of indicated change polygons, to characterize the polygons in various categories by an additional attribute, to keep them during the check phase and to sort them out only in a final stage by certain criteria.

Automatic labeling:

Initially, small polygons were marked by reference numbers in an attribute "CH_SWITCH" in case of areas less than 0.5 ha and between 0.5 ha and 1.0 ha, in order to exclude them at first from further plausibility checks.

Other marks in "CH_SWITCH" were awarded for several categories of elongated objects. For this purpose, a form parameter "rat_area_l" was calculated by the ratio of the polygonal area to its circumference. After various tests, a threshold was defined by which all polygons were treated as "small objects" if showing a parameter value rat_area_l < 20. Other classifications of small objects related to their aerial values between 1 ha and 2 ha, between 2 ha and 3 ha, up to sizes of about 8 ha. The large-area polygons with more than 5 ha area, also labelled as “small polygons”, contained often a broader patch with a lineament-like narrow extension. This type of polygons was manually checked and divided if necessary.

By only marking and not removing from the record, the small-area and small polygons continued to be available in complicated change situations. Thus they could be included in an appropriate manner for the description of complex change processes.

Formally those polygons were specially highlighted, where the CLC category for 2006 was set to “0” in the attribute CLC_ST06, or which had the same CLC attribute in 2006 as in 2009 (in the attribute "CLC_UPD13"). This case indicated a partial area without a change.

All other polygons (with the small-area and small polygons specially marked before) were initially given a temporary "CH_SWITCH" value of 88. All such labeled polygons were subject of various tests or manual changes, after which the value of CH_SWITCH was adjusted depending on the result (real change, no real change, certain group of real change).

Plausibility checks:

In the following, several investigated change categories are listed, resulting after the automatic processing approach, which often do not represent real changes. A review and appropriate action is necessary, as experience has shown (in the short description of the change categories in discussion, the state in 2006 is noticed on the left and the state in 2009 on the right):

<u>211-> 142 and 231 -> 142:</u> As sports and leisure areas (CLC class 142) are usually not included in any of the masks like in the building mask or the forest mask for 2006, these areas are covered by arable land and grassland (211 and 231) when using a threshold classification. Thereby incorrect changes can be the result. Thus, for example, glider airfields (as part of 142) will be recorded in 2006 as part of the class 231, but no real change is represented in this case. In order to include the change process of the formation of new golf courses on former agricultural land, manual checks are necessary by using additional web service information.

<u>211-> 242 and 231 -> 242:</u> By the inclusion of a possible change process 231 -> 242 (ranked 17 in Table 7), several change areas are indicated which are in most cases no real changes. To a lesser extent, however, a dominant grassland use for 2006 is shown in the associated 231 areas, which then corresponds to a real change. As the minimum mapping unit is 1 ha in DLM-DE 2009, the heterogeneous agricultural class 242 occurs only in a small extent in DLM-DE 2009.

xxx-> 512: Indicated changes of various CLC classes in 2006 to water bodies in 2009 are usually based on not recognized mixed pixels as part of the water areas in the water mask of 2006, so that these areas are displayed as change areas. However, a review is necessary by zooming the polygon limits overlay on the IMAGE2006 data because real changes to lakes exist, e.g. with former mining areas or arable land in 2006 changed to new water bodies. Another form of change to water bodies can be the rewetting or re-watering of grassland or wetlands.

222 -> 211 and 222 -> 231: The transformation of perennial crops (fruit tries) to arable land was derived in the automatic assessment directly from the areas with CLC class 222 in 2006 (25 ha MMU). This coarse detection in 2006 must be checked on the basis of satellite data of 2006 and additional data. In a regional approach, also adjacent polygons outside of the detection of CLC2006 (25 ha MMU) can be taken into account that may indicate a wrong status of grassland in 2006.

Further checks and corrections:

For the derived change areas in agriculture, with the assignment of arable and grassland areas in 2006 (exchange processes 211 <=> 231), it was found that a full-area check was necessary to label the indicated changes as real or not real. In special landscape situations, the thresholds for defining 211 and 231 can lead to incorrect assignments. For these change types, an export of potential change polygons (211 -> 231 and 231 -> 211) and a separate check proved to be very useful. The change polygons in agriculture were scrolled through in a systematic way, with the aid of defined test strips and in scale ranges from 1: 30000 to 40000, and non-real changes were marked.

On the one hand, background information on the temporal AWiFS statistics was used for the decision if to confirm a change or not. On the other hand, the three high resolution satellite scenes of band combination (NIR, SWIR, VIS-R) in RGB were used, that were the mosaics of LISS-III summer, LISS-III spring and Landsat summer. When required, also other levels of information from the Internet were included, such as information from the Google Earth Archive. Figure 23 shows the GIS layers used in the verification process of changes in agriculture.

An accumulation of apparent changes 211 -> 231 or 231 -> 211 can also be a result of an unsatisfactory data situation in 2009 in terms of arable land / grassland separation, so that a not sufficient multi-seasonal cover could have led to overestimations or underestimations of grassland or arable land in the year 2009, by that leading to apparent change areas between 2006 and 2009. In these kinds of situations, it is then more important to determine well the status in 2006 in terms of the later comparison with the status in 2012.

Failures in the automatic assessment of the distribution of 211 and 231 were more frequent in meadows situated in river floodplains, thus delivering wrong changes in comparison to DLM-DE2009. This is often due to the fact that in certain periods of the year, usually in spring, flood levels disrupted the temporal characteristics of the NDVI values of AWiFS. In these cases, especially the range of values (and the standard deviation) reached a level as shown for arable land.

An example which shows large influences in the temporal statistics of the inundation areas is presented in Figure 24, showing the floodplain of the river Havel. Only by comparative visual checks with the LISS-III-scenes of spring and summer and the Landsat summer scene, the distortions of the temporal NDVI statistics can be recognized. Partly, misallocations of arable land would be made here.

The inspected polygons in agricultural land, with labels of real / not real change polygons, were subsequently merged back into the total change polygons using the ArcGIS update function.

Figure 23: Data basis for the manual improvement of the generated change areas - an example in a subarea of the macro region MV (Mecklenburg-Western Pomerania, Brandenburg): Temporal statistics of AWiFS NDVI time series; statistics with an overlay of forest, water and urban mask; satellite data of LISS-III (spring and summer). Sources: Satellite data © ANTRIX, Euromap / GAF AG (LISS-III).

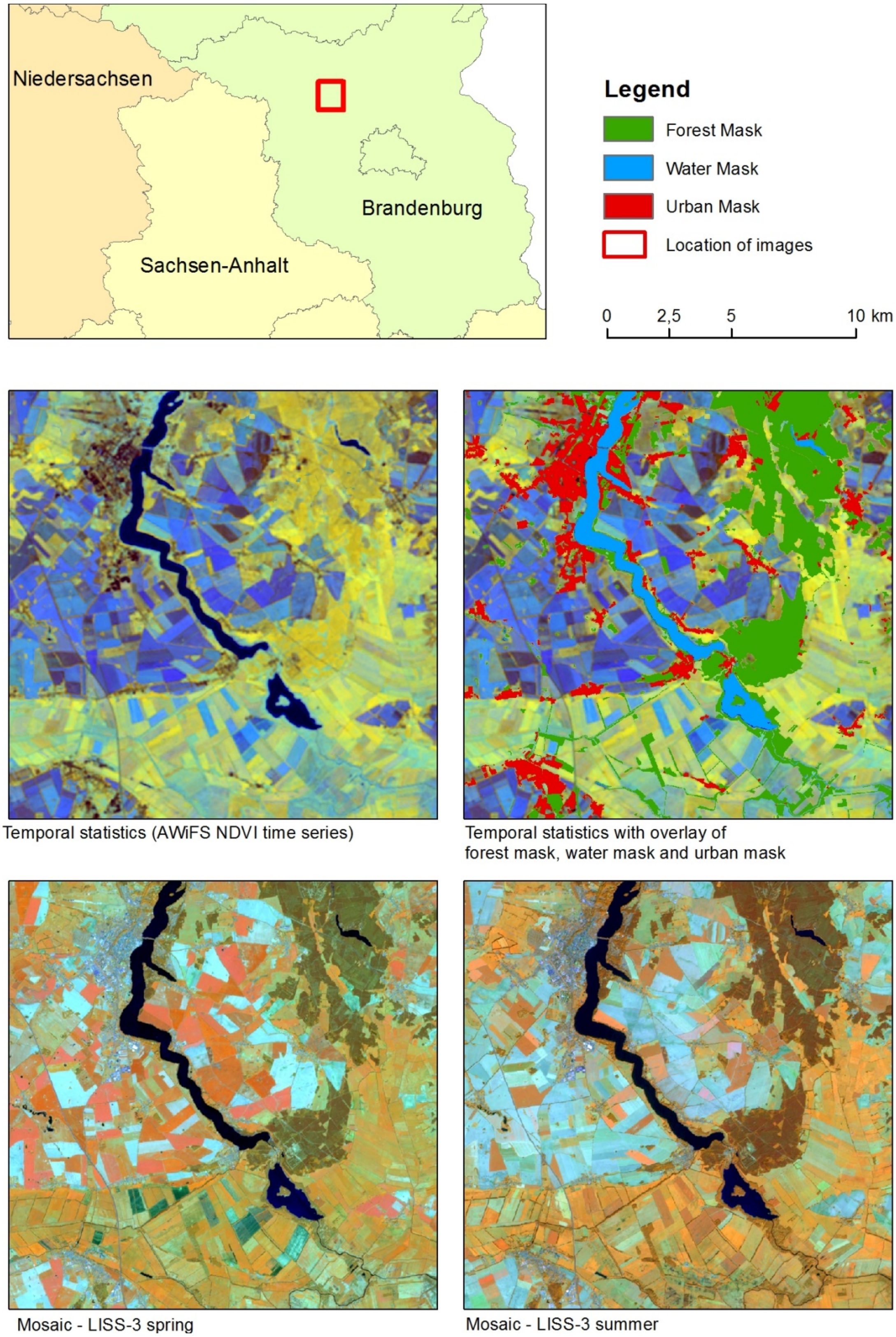
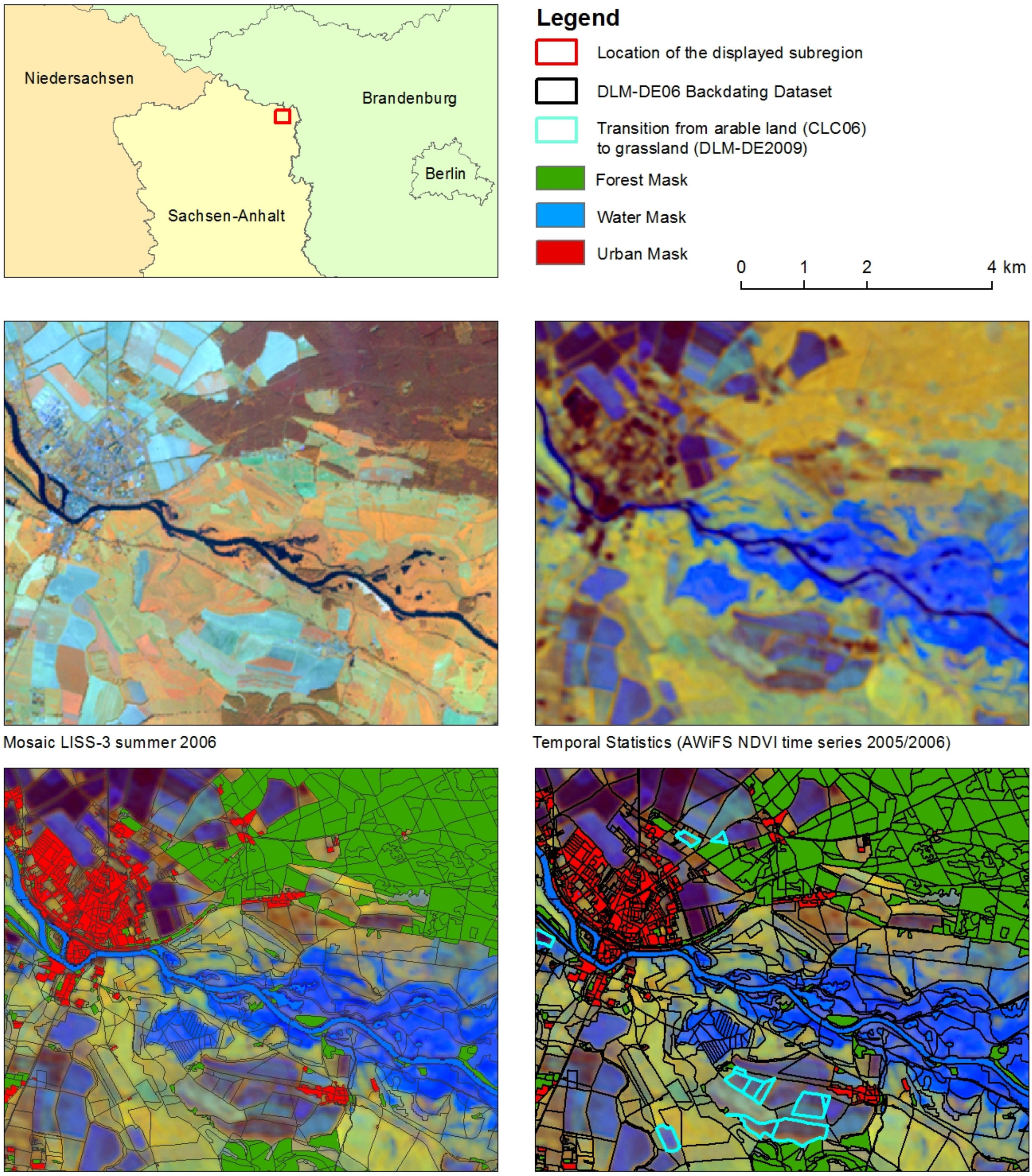


Figure 24: Changes of arable land (CLC 211) in 2006 to grassland (CLC 231) in 2009, an example in the area of the Hanseatic city Havelberg in the macro-region ST: data from LISS-III (summer, u. l.); temporal statistics of AWiFS NDVI time series (u. r.); statistics (l. l.) overlaid with forest, water, urban mask and DLM-DE2006_Backdating; added marked changes from arable land to grassland in blue (l. r.). - Note the blue appearing grassland sites in the Havel area which are likely a result from the spring floods with larger temporal changes of NDVI and could incorrectly indicate arable land. Sources: Satellite data © ANTRIX, Euromap / GAF AG (LISS-III, AWiFS); geobasis data © German Federal Agency for Cartography and Geodesy (www.bkg.bund.de).



Mosaic LISS-3 summer 2006

Temporal Statistics (AWiFS NDVI time series 2005/2006)

Temporal Statistics with overlay of forest mask, water mask, urban mask and the DLM-DE06 Backdating dataset.

Temporal Statistics with overlay of forest mask, water mask, urban mask and the DLM-DE06 Backdating dataset; marked in turquoise: transition from arable (2006) to grassland(2009).

6 Examples of final products

After completion of the checks and manual improvements of the change areas regarding the status in 2006, percentages of change areas resulted in values between about 2% and 3% for the macro-regions (Table 12). The areas of open sea and tidal zones in the coastal regions (CLC classes 423, 521, 522, 523) were not included in this accounting. The relatively high proportion of changes in the macro-region SH (Schleswig-Holstein, Lower Saxony, Hamburg and Bremen) is mainly due to detected changes in agriculture (with changes in both directions).

Table 12: Percentage of change areas in the CLC2006_Backdating dataset related to the total area of the corresponding macro-region.

Macro region	Total area		Change		
	Total area (km²)	Number of polygons	Rates of changes (area in km²)	Percentage of changes (%)	Change (number of polygons)
BW (BW)	35752.0	2024336	691.40	1.93	25431
BY (BY)	70725.0	1524160	1652.6	2.34	42712
MV (MV. BB. BE)	53714.5	1187757	1357.3	2.53	19564
NW (NW. SL. RP. HE)	77678.4	3592470	1636.4	2.11	53080
SH (SH. HH. NI. HB)	63741.2	1992042	1994.2	3.13	51597
ST (ST. SN. TH)	55279.0	1695683	1101.5	1.99	22916

For some types of changes, some results of change areas are to be shown in comparison to the state of DLM-DE.

Figure 25 shows a region in the Southeast of Baden-Württemberg with change areas in agriculture. Shown are overlays of polygon boundaries on satellite image products of 2006 and 2009, with the labeling of change classes according to CLC. The figure in the lower right shows in the background the three statistics bands of the temporal NDVI statistics (minimum, mean, standard deviation) in RGB presentation.

In a further example, a sub-region in North Rhine-Westphalia is shown with change polygons in the forest, related to the hurricane Cyril in January 2007. Large areas in the Sauerland region had been devastated, but also the neighboring Northern Hesse was highly affected (Figure 26). Other change areas are a result of transitions from afforestation (class 324) into older forest classes (311, 312, 313), partly developed on previous storm damaged areas of the 1980s and early 1990s.

Figure 25: Result of the delineation of change areas in agriculture, Region Aulendorf, district Ravensburg. Concerning the CLC classes, see Figure 1. Sources: satellite data © ANTRIX, Euromap / GAF AG (LISS-III, AWiFS); USGS/NASA (Landsat).

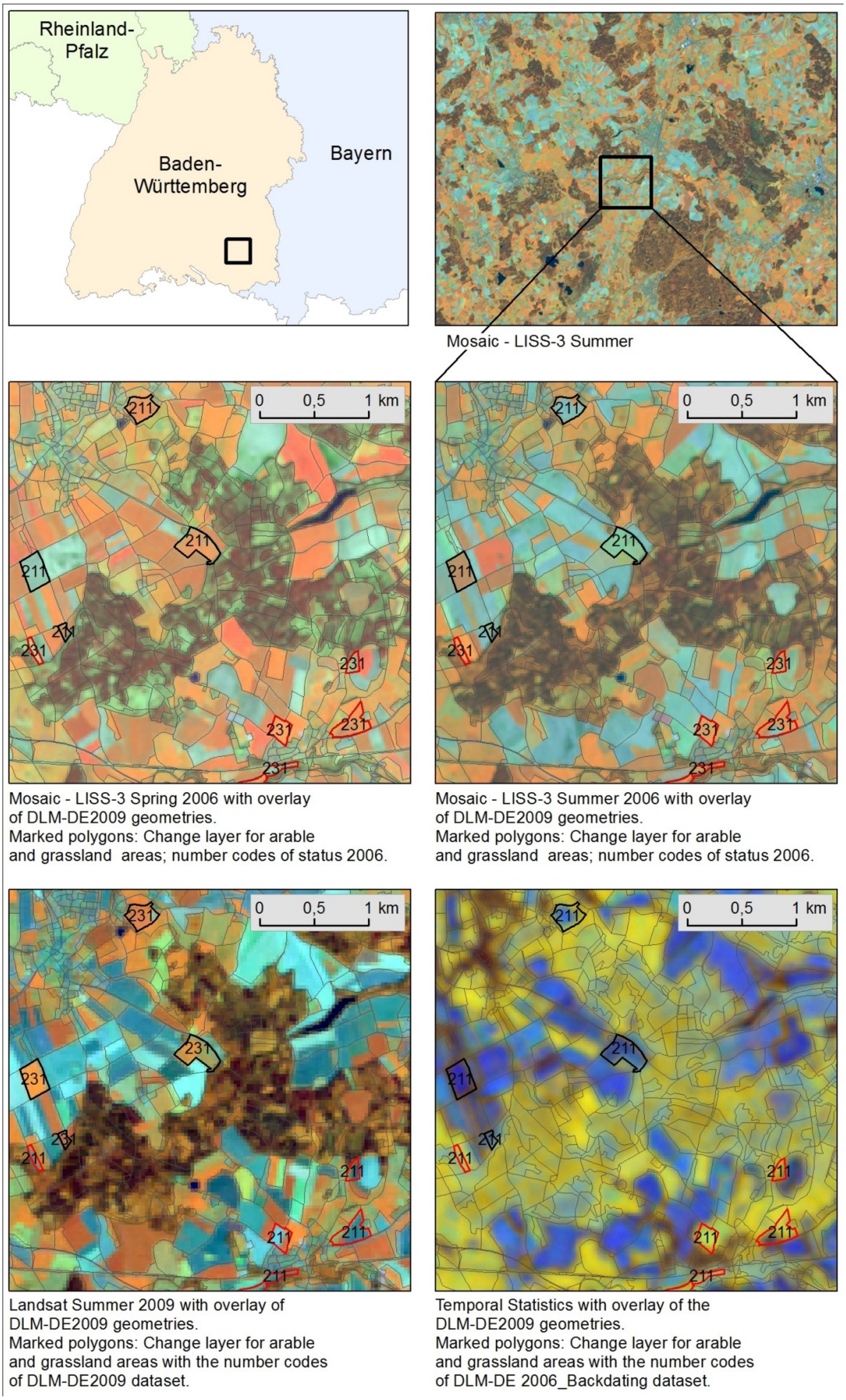
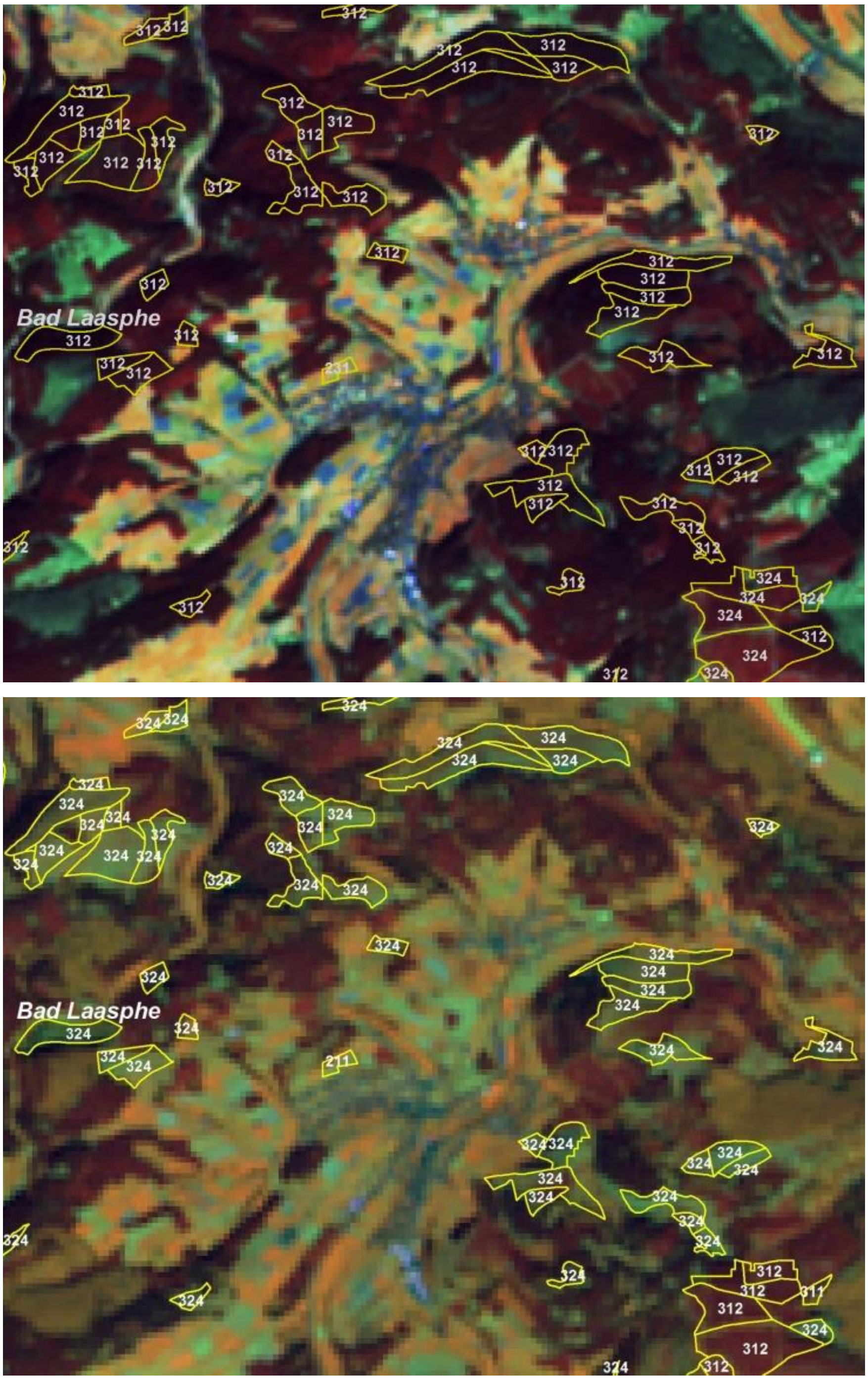
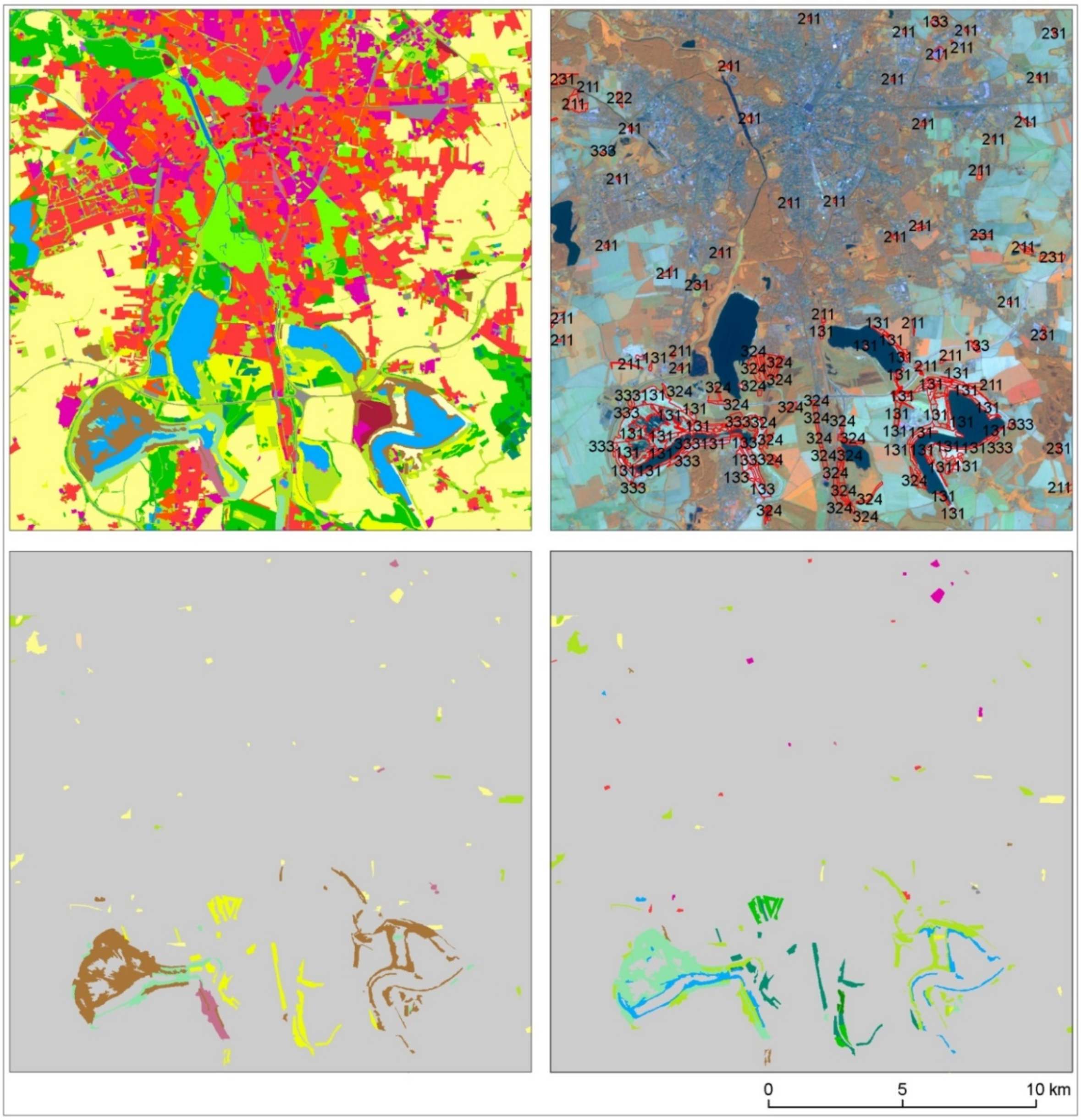


Figure 26: Example of changes in forest cover due to storm damages in Sauerland region (Hurricane Cyril from 18 / 19 January 2007), with the transformation 312 -> 324. Above: LISS-III scene of 2006 (spring) with the change areas in the state of 2006; below: Landsat summer scene of 2009 with the status of 2009. In the Southeastern region, several change areas were detected as transitions 324 -> 312 (transition of young forest areas to coniferous forest). Sources: Satellite data © ANTRIX, Euromap / GAF AG (LISS-III); USGS /NASA (Landsat). Geobasis data © German Federal Agency for Cartography and Geodesy (www.bkg.bund.de).



The former lignite open-pit mining areas in the South of Leipzig were gradually closed in recent years. They are characterized by different activities of recultivation and flooding which led to new lake landscapes and recreational areas (Figure 27). New urban structures (industrial and commercial areas and public facilities) can be distinguished, mainly in the East of the city.

Figure 27: Exemplary results of CLC2006_Backdating for the South of Leipzig region and the new Leipzig lakelands: Development of numerous water bodies and recreation areas as a result of recultivation and renaturation of former lignite open-pit mines. Upper left: CLC2006_Backdating dataset, color codes see Figure 1; upper right: LISS-III summer scene with overlay of change areas and the codes for the status 2006; lower left: changes between 2006 and 2009 in the status of 2006; lower right: changes between 2006 and 2009 in the status of 2009 (color codes see Figure 1, as well). Source: Satellite data © ANTRIX, Euromap / GAF AG (LISS-III).



7 Consideration of data quality

Geometry:

With respect to the geometry of the satellite data from 2006 as input data, it can be assumed that the location accuracy is about one pixel, corresponding to approximately 20 m for LISS-III data and about 30 m for Landsat data.

The AWiFS data with a pixel resolution of about 60 m had in general a fitting accuracy to the LISS III data of the order of less than or equal to 60 m . But partly there existed local offsets of about 60 m or slightly above concerning the AWiFS data of different dates. The AWiFS data were combined with the high-resolution data via the sub-segments on the basis of LISS-III and Landsat data; they were not used for the delineation of different objects and land cover types. The AWiFS data were used for the subdivision of the agricultural classes, thus they delivered primarily thematic information. Small-scale agricultural land patterns can lead to geometry-related problems in relation to the geometric resolution of 60 m.

Agricultural classes:

The inspection of the automatically derived change areas with interactive improvements were not only performed, as initially planned, in certain "hot spots" of expected change regions such as in large mining areas with various recultivation stages. In graduated forms (and especially with respect to the major change areas), this inspection was performed for all types of change classes.

Concerning the agricultural classes and their spatial distribution (arable land 211 and grassland 231), it was found that a full-area inspection was necessary, for which, however, a compromise scale had to be introduced between 1:30,000 and 1:40,000. Due to the different variables such as soil type, soil moisture, distribution of crops and crop rotation, the deduced threshold values based on temporal statistics (AWiFS NDVI) did not always well describe the boundaries of grassland and arable land. The derived statistics parameters minimum, mean and standard deviation were dependent on the representativeness of available periods in the AWiFS records and also on the situations regarding local cloud gaps or gap-free coverage by 4 to 7 scenes. In the combined use of the AWiFS indicators and the three mosaic variants of LISS-III (spring and summer) and Landsat (summer), a significant improvement in the allocation of agricultural areas was possible, concerning authentic or not real changes. It can be assumed that an automatically derived arable land / grassland separation can be optimized by an improvement in the seasonal overlap, e.g. by improved time series of the future Sentinel-2 data of the ESA system.

Forest classes and other classes:

The changes in forest areas (particularly affected by storm damages) were not always clear transitions (primarily 312 -> 324); often gradual damages were observed. Sometimes, a further damage development was observed or a continuous preceding clearing of the stocks between the scenes of 2006 and the extended seasons of 2005 to 2007. Frequently, previously damaged or partially opened stocks are the first affected at the next storm event. The automatic sub-segmentations were not always clear concerning the geometries. Partly, the sub-segmentations were improved by manual digitization to some extent, especially for large-area polygons. For that, a combined approach was helpful, with clicking through indicated areas starting with large ones on the one hand, and corrections on the basis of priority areas in terms of certain changes on the other hand.

Even concerning changes by urban developments (construction of new residential areas, new industrial and commercial areas), a building site might just be indicated by first activities at the one scene (e.g. in spring 2006), and the segment might possibly still to be characterized as arable land; in another scene, in summer 2006, the segment might be much more visible as the site has evolved to a construction site (CLC class 133). Primarily, it was attempted to use the summer scene in 2006 as reference period in case of various scenes around 2006. For automatically recorded transitions 211 -> 121 which were already associated with some first sealing, the CLC class 133 was selected as a transitional class during the improvement phase.

„Hot Spots“ of changes:

Large mining areas and the surrounding restoration sites were inspected and manually improved in the regional context, especially the lignite mining areas in North Rhine-Westphalia and Saxony, Saxony-Anhalt and Brandenburg. Here the integration of information from the surrounding polygons was necessary to grant a consistent assignment of the various recultivation stages. A similar approach was performed for the characterization of successional stages in former military training areas (CLC classes 333, 321, 324, 311, 312, 313).

Also, several major permanent crop areas with partial conversions to cropland from 2006 to 2009 were revised in the regional context (e.g. in the region Werder upon Havel, Brandenburg), which was necessary to improve the documentation of these developments.

A special situation was observed concerning the large dead wood areas in the Bavarian Forest National Park, which were caused by bark beetle infestation and were connected with different stages of damages, but also of regeneration. Also here a regional revision was necessary.

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