Update of the European High-resolution Layer of Built-up Areas and Soil Sealing 2006 with Image2009 Data

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Abstract. The European Environment Agency (EEA) requested from the FP7 geoland2 project a year 2009 update of the European high resolution layer of built-up areas and soil sealing, which was derived from the IMAGE2006 satellite coverage. Methodological development of the automated change detection approach is covered by the Core Mapping Service (CMS) EUROLAND, which further develops the GMES Land Monitoring Core Service, including advanced approaches for continental land cover and land cover change mapping. The objective is to derive a comparable product of highest possible quality, showing changes of the built-up area between 2006 and 2009 as well as changes in the imperviousness degree within the 2006 sealed surfaces. As for the 2006 soil sealing layer, bi-temporal Spot and IRS-P6 satellite data with a nominal pixel size of 20m (IMAGE2009) are being used. The 2006 built-up area resulted from a combined approach based on automatic image classification and subsequent visual editing. The imperviousness degrees 2006 were derived based on the NDVI with a visual calibration approach applied individually to each data set. Both, the 2009 update of the built-up area and of the imperviousness levels are based on the calibrated NDVIs of Image 2006 and of Image2009. For this purpose a procedure was developed that automatically derives calibrated NDVIs for Image2006 and 2009, both based on the original imperviousness degrees of Image2006. A further automatic procedure was developed that compares the resulting calibrated NDVIs of Image2006 and 2009 and derives built-up change candidates using a set of rules and thresholds. Up to this point, the update procedure is completely automated using the ERDAS Model Maker. The resulting built-up change candidates are then visually edited, in order to exclude false alarms and to supplement change areas not captured by the automatic procedure. This leads to the final new built-up area 2009. The update of the imperviousness levels within the built-up area of 2006 is done by deriving the imperviousness differences between Image2006 and 2009 and applying both spectral and spatial thresholds as to which differences constitute likely true changes. The results of this geoland2 CMS EUROLAND activity shall serve as an essential input to support Europe-wide urban sprawl assessment for EEA and user DGs (i.e. DG REGIO, DG ENV and DG Agri) and to support Member States in upgrading their national data bases.

Keywords. Geoland2, Euroland, change detection, satellite data, built-up areas, soil sealing, Impervious Surface Area (ISA)

Introduction

Earth Observation based (EO) land monitoring reveals a dramatic increase of land take for housing & transport infrastructure: Between 1990 and 2000, the growth of urban areas in Europe amounted to over 8.000 km², corresponding to a yearly growth rate of 0.6 % (EEA 2006). If this high speed growth went on, it would lead to a doubling of the European urban areas in this century with a further aggravation of all negative consequences such as land fragmentation, loss of valuable agricultural soils, increase of surface run-off, etc. Consequently there is an urgent need to monitor these changes and raise awareness and readiness to counteract these developments.

The urban area and sealing was the subject of the GMES (Global Monitoring for Environment and Security) Fast Track Service Precursor (FTSP) on Land Monitoring, a project conducted from May 2007 to December 2008 (Tinz 2009). It covered 5,8 Mio km², including the 32 EEA (European Environment Agency) member countries plus six further countries. The project was based on Image2006 data, a bi-temporal dataset of HR (High Resolution) EO datasets (IRS LISS-3 and Spot-4) with a nominal ground resolution of 20m. Output of the project was the first pan-European dataset of built-up areas and the degree of soil sealing. As state of the art expression, the term ISA (Impervious Surface Area) or % ISA will be used hereafter and sealing only when referring to the FTSP Sealing project.

In 2009, a FTSP-Sealing Enhancement project was carried out, aiming at specific modifications and corrections of the built-up area including gaps and obvious commission errors specified by the member countries. Output was an "enhanced" FTSP-Sealing layer, where CLC (CORINE Land Cover) class 1.3x elements (e.g. quarries) as well as obvious commission errors were removed, and gaps were closed.

Also in 2009, EEA requested CMS (Core Mapping Service) Euroland to generate an update of the built-up and impervious layer using Image2009 data. The update is intended to serve the European Environment State and Outlook Report (SOER2010), to support various reporting & management obligations (e.g., ESDP – European Spatial Development Perspective, UTS – Urban Thematic Strategy, and others), and to support national mapping activities.

Requested outputs are updated status maps and change maps of the built-up area, as well as status and change maps of imperviousness in 20m resolution, and an updated 1ha "European layer" of built-up areas and degrees of imperviousness. As for the original FTSP output, a thematic minimum accuracy of 85 % was requested, to be validated in 1ha cells. The mapping is currently being performed by nearly the same consortium partners as the FTSP2006; production is going on after almost complete image delivery to the service providers by ESA. Thus, this paper describes work in progress and not yet final results.

1. Methodology

In remote sensing, the degree of imperviousness can be estimated with proxy parameters that quantify the cover of green vegetation, which en gross can be considered inversely correlated with the degree of surface imperviousness in urban or built-up areas. Consequently, vegetation indices such as the NDVI - Normalized Difference Vegetation Index have frequently been used to estimate % ISA in urban environments (Kawamura et al. 1997, Fung et al. 2000, Slonecker et al. 2001, Braun et al. 2003). Compared to other VIs the NDVI has several advantages specifically for this purpose: First, it is well suited to reduce illumination influences and extract vegetation information in shaded areas (Chen et al. 2005) that are frequent in urban areas. Second, the NDVI shows little differentiation among various types of vegetated surfaces, as it is (due to the first reason) not very sensitive to vegetation structure. For the objective of estimating the amount of area covered by (any) vegetation, this is definitely of advantage, as the strength of the vegetation signal is not much influenced by the type of the vegetation. Third, the NDVI is known to be rather sensitive to the bare ground, thus it has the potential to distinguish even small amounts of impervious from fully vegetated surfaces. Its sensitivity to different types of impervious cover types (asphalt, concrete, tiles, etc.) however raises the unsolved question of understanding the variations of the NDVI values with differences of canopy background signals. Nevertheless, the NDVI was chosen as a commonly applied, state of the art index. It has an additional advantage that it is only based on the Red and the NIR bands (limited atmospheric distortion) and is free of further assumptions.

1.1. Methodology of the FTSP 2006

At this point, the methodology applied for derivation of the FTSP 2006 Built-up and Sealing Layer shall be shortly summarized, before the change detection methodology for the Update 2009 is described.

The built-up area was derived with an iterative, hybrid ISODATA/Maximum Likelihood classification of the bi-temporal 2006 imagery (using all 8 bands – Green, Red, NIR, SWIR * 2), based on a minimum of typically 50 urban training areas spread over different types of urban surfaces throughout each bi-temporal image data set (referred to as Working Unit – WU).

The automatically derived classification results were visually post-edited in order to correct for omission and especially commission errors. The built-up area was retrieved from a pure land cover aspect, and thus does not explicitly include urban green areas. Nevertheless, “green” pixels are not completely excluded.

The NDVI images were masked with the derived built-up area and then scaled to 8bit using in all cases the same scaling parameters. Thus, similar NDVI histograms with easy to handle integer values were generated for the built-up area of each WU, though still varying with the different urban surface properties of the WUs.

Based on visual image interpretation, the values of the scaled NDVI were determined for each WU that mark the 100 % and 0 % ISA points in the NDVI histogram. To find the 100 % value, the largest NDVI value that could be interpreted as unvegetated surface had to be found. This was typically done in larger cities using large impervious objects such as city centres, train stations, airports, industrial areas, etc. Likewise, the smallest NDVI value that represented 100 % vegetation cover or 0 % ISA was derived. In this case, the upper (right) end of the main NDVI histogram body (without the upper tail) was taken, based on the fact that within the classified built-up area some vegetated pixels are contained and that only built-up surfaces were included in the NDVI image, as mentioned above.

Using these two NDVI values, the degrees of imperviousness were computed and scaled to a range from 1 % to 100 %, assuming a linear increase of imperviousness with decreasing NDVI between the 1 % and the 100 % ISA. The high precision of 1 % increments was requested as nominal output in order to enable a flexible selection of broader ISA categories for different users and purposes.

Figure 1 shows a small part of Innsbruck as an example for the FTSP 2006 map of imperviousness. The class “0 % imperviousness” was actually not included in the built-up area.

1.2. Methodology of the update 2009

For the 2009 update of the 2006 impervious layer, the development of a highly automated approach was indispensable to meet all requirements and constraints of the project, especially to yield a result of maximal accuracy and consistency. With an average urban sprawl of 0.6 % per year (see above), total growth of the urban area amounts roughly to 2 % from 2006 to 2009 in Europe. Vienna with approximately 400 km² for instance has an expected growth of roughly 8 km² during the update period. Taking for instance an average size of the new built-up sites of 5000 m² (as a rather large figure) and assuming that 7 km² growth may be assigned to building constructions, this would result in 1400 new built-up elements! Thus, the method chosen must be able to automatically derive changes of the built-up area, as a purely manual mapping approach is not a feasible option.

With the exception of geometric pre-processing, the methodology was developed and implemented with the ERDAS Model Maker, aiming at the highest possible production efficiency and quality.

The Image2009 data are precisely co-registered to Image2006, with an RMS of less than 0.5 pixel (<10m). Geometric pre-processing is done by Eurimage and DLR. For each scene of Image2009 a cloud/shadow mask is produced by the service providers. The latter is needed to exclude these areas from processing and serves as meta-information with regard to coverage of the area with usable data.

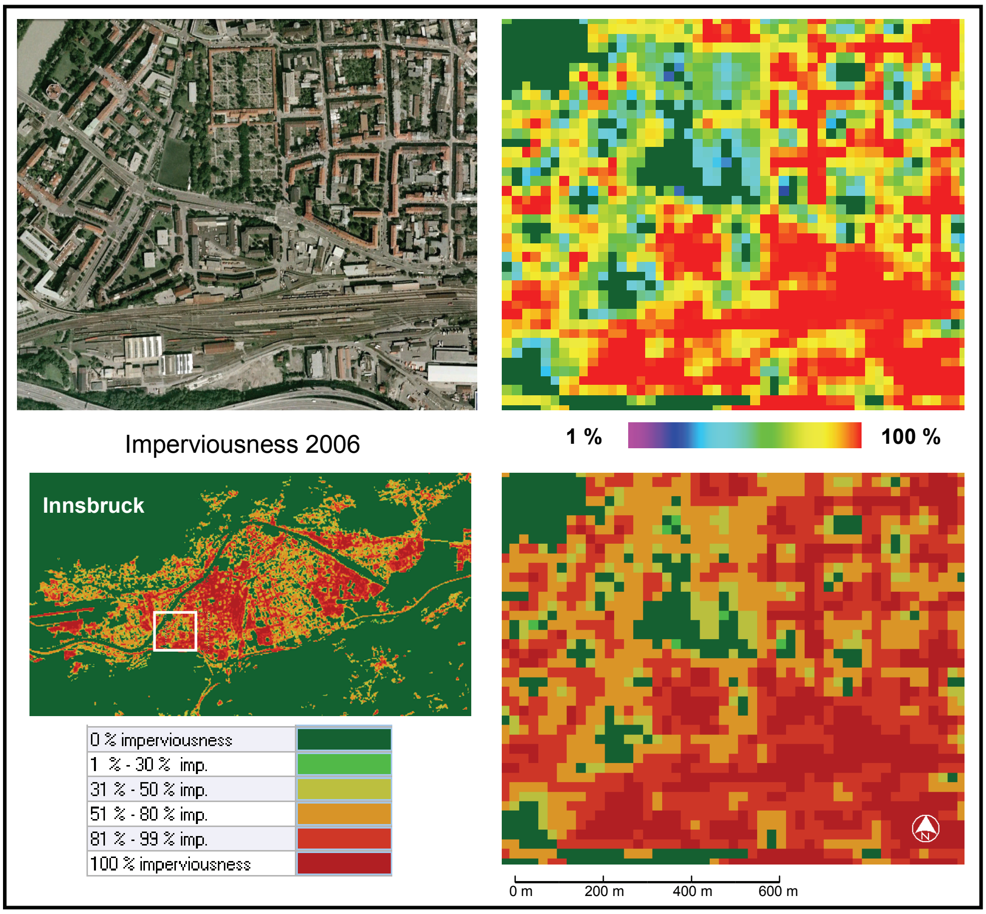


Figure 1: Degrees of Imperviousness 2006, Innsbruck; upper right: continuous scale.

The update procedure starts with the processing of the individual Image2006 and Image2009 data, but proceeds then to the processing of larger Working Regions (WR) by mosaicking the individual results. Small countries (e.g. Austria, Czech Republic, Switzerland, etc.) can thus be processed in one piece, once the scene-dependent steps are performed. Figure 2 illustrates the relation of WUs (Image 2006), scenes of Image 2009 (only one coverage shown), and the WR at the example of Estonia (45.227 km^2). WRs can have a size of more than 100.000 km^2.

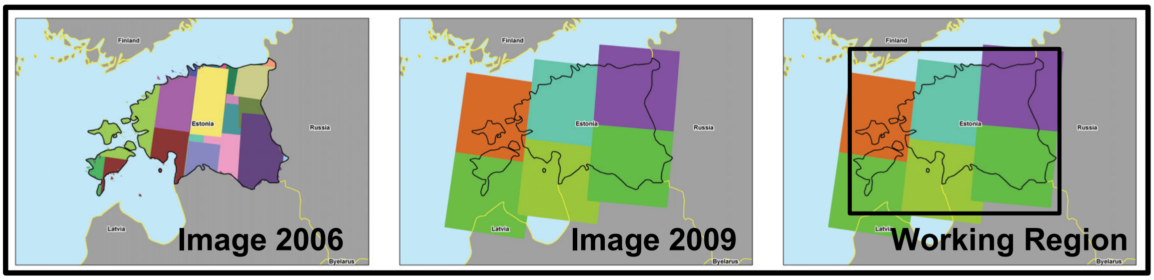


Figure 2: Data organisation 2006 versus 2009 (Example: Estonia)

Scene-dependent is the derivation of calibrated NDVIs for Image2006 and Image 2009, covering the entire image area (FTSP 2006 had only produced ISA levels for the built-up area 2006). The calibration re-builds the ISA degrees derived in FTSP 2006 based on the assumption that ISA changes within the built-up area 2006 in this rather short period do not lead to significant changes of the overall ISA (for larger time intervals, the calibration should be based on unchanged areas, which had to be estimated in an iterative calibration and thresholding approach image by image). The calibration is performed fully automatically, in a sequence of histogram matching steps and implemented in one ERDAS model for 2006 and another one for 2009. Control files are automatically created along with the NDVIs. They indicate the difference between the original sealing degrees of FTSP 2006 and the newly derived values. Even though the developed ERDAS models themselves are highly complex, their application is straight forward and is done in batches, one per WR. Thus, once the input data (Image2006, Image 2009, cloud masks, FTSP2006 sealing degrees) are compiled and properly organised, the NDVI calibration is performed automatically, in one batch for small countries or WRs.

The calibrated NDVI images for 2006 and 2009 are then mosaiced to WRs. For 2006, the NDVI maximum is taken per pixel outside built-up areas, for built-up areas the original FTSP 2006 sealing degrees. For 2009, a minimum- and a maximum NDVI mosaic are generated in order to derive the range of ISA levels. Image2009 data are not organized in non-overlapping bi-temporal WUs as the Image2006 data, but processed as entire scenes. The resulting multiple overlapping image information is entirely used, so as to minimize the final cloud cover 2009 by all possible cloud substitutions, and to maximize the NDVI wherever possible due to suitable acquisition dates (phenological states). Mosaicing (including Max/Min derivation) is also implemented in two ERDAS models, one or 2006, and one or 2009. Thus, the service providers arrive at calibrated and mosaiced NDVIs for each WR after four technical operations (comprising actually a multitude of single functions).

In the next step, potential change areas of the built-up area are derived, using the calibrated maximum NDVIs of 2009 and 2006. The changes comprise new built-up sites and areas that are clearly vegetated in 2009, but erroneously included in the built-up area 2006, i.e. commission errors 2006. These potential changes and errors, respectively, are derived based on a complex series of rules, % ISA and % ISA-difference (2009 -2006) and object size thresholds, buffers, filters and image intersections, implemented in one ERDAS model. Output is a raster file at WR level, containing several built-up change candidate classes of different probabilities, the built-up area 2006, cloud-related meta-information, and specific change classes of the FTSP-Sealing Enhancement project.

Using this raster overlay and Image2009 the manual post-editing of the changes derived in the last step is performed. This is the most time-consuming part of the work and takes a multiple of the time needed for the automatic processing steps. This part of the work was prepared and coordinated by various training sessions among the project responsible of the service providers, followed by training and supervision of the interpreters at the individual production sites. During post-editing, no-data areas of 2006 (“bi-temporal” clouds) that are cloud-free in the 2009 imagery, are (predominantly) visually mapped.

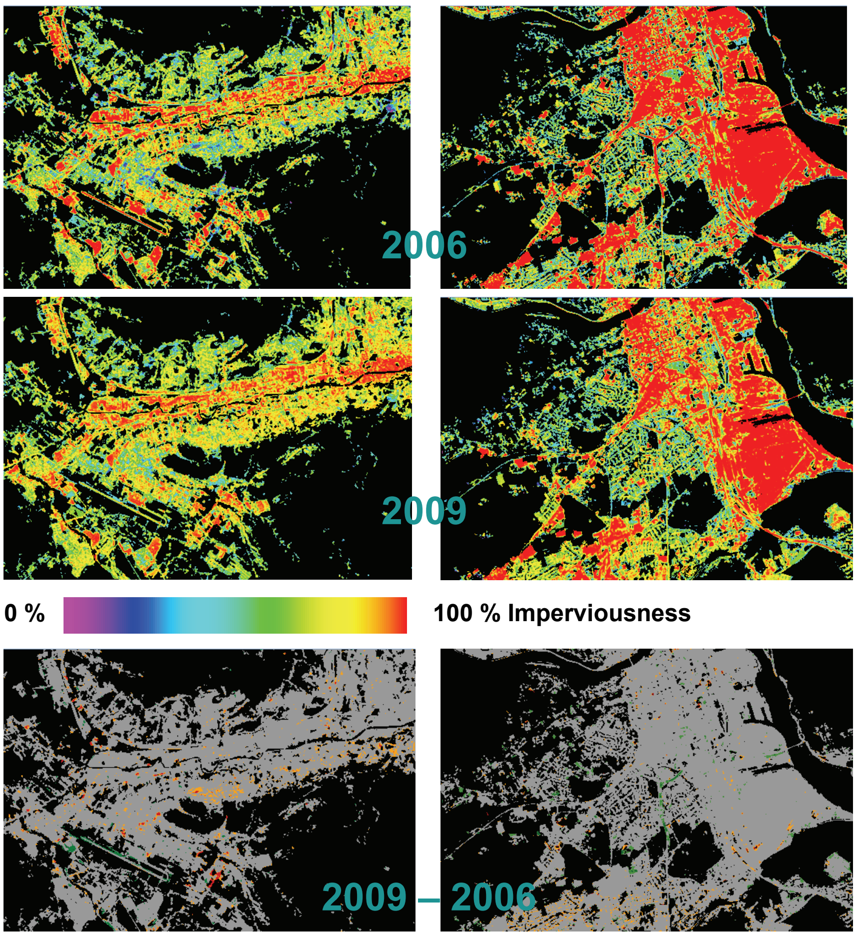
Once the visual editing is finished, two further methodological steps have to be performed: The first will be the separation of the changes into so-called “technical changes” and real changes. This is straight forward for commission errors, where all commission errors are regarded as non-built-up areas 2006 (cases where real removals of buildings or other sealed surfaces occurred are not retrieved with this project and need approaches at finer scales; however there will be decreases of the imperviousness from 2006 to 2009). The separation of true new built-up elements from possible technical changes (gaps closed due to the different mapping method) on the other hand, is less straight forward. A rule-based approach using spectral (NDVI difference) and spatial (surface size of elements) thresholds will be applied to estimate the true change. The second step will be the derivation of the 2009 degrees of imperviousness as well as the changes of imperviousness between 2006 and 2009 within the built-up area 2006. The former will be based on the calibrated Minima and Maxima NDVI image mosaics of 2009, and the 2006 imperviousness. ISA differences 2006 to 2009 will also be derived applying NDVI difference and surface size thresholds. The choice of the thresholds applied to the NDVI difference depends on the accuracy of the reproduction of the ISA degrees 2006 with Image2009. The question in this regard is what is the portion of noise and fuzziness of the calibration results and where does significant change of imperviousness start?

2. Intermediate results

As mentioned in the introduction, the works described in this paper are in progress, thus only intermediate results can be shown.

The key question of the entire procedure is how accurately can the 2006 imperviousness levels be reproduced for 2009? This question was assessed by evaluating the statistics of the difference images of imperviousness degrees between 2006 and 2009. During the method implementation and first large area applications, it turned out that ca. 90 % to > 95 % of the pixels have deviations of maximal 25 degrees of imperviousness (on a scale from 1 to 100) between 2006 and 2009. These are due to geometric shifts, different phenological states of the vegetation, and – locally – to true differences of the vegetated area and commission errors 2006. The calibration model itself works highly accurately, as the imperviousness degrees 2006 can be reproduced with a deviation of typically 0 to 1 degree when using the same images. Thus an imperviousness difference threshold of 20 to 25 % may be regarded as an appropriate lower limit for significant changes between 2006 and 2009.

Figure 3 shows two examples with impervious degrees 2006, 2009, and difference images 2009-2006; for the latter, the average imperviousness 2009 (mean of Min and Max) was used.



Class_Names	Color	Percent
non built-up 2006		0.00
> 50 % decrease		0.03
26 - 50 % decrease		1.11
- 25 % to + 25 % de-/increase		93.74
26 - 50 % increase		4.45
> 50 % increase		0.68

Class_Names	Color	Percent
non built-up 2006		0.00
> 50 % decrease		0.43
26 - 50 % decrease		3.34
- 25 % to + 25 % de-/increase		91.76
26 - 50 % increase		4.12
> 50 % increase		0.35

Figure 3. NDVI calibration results for Sarajevo (left) and Linz

Figure 4 depicts an example of the automatically produced change candidate images. Candidate classes 1 and 2 (increases of the built-up area) are classes with a high probability and are deleted during post-editing where they are considered wrong, whereas class 4 is a lower probability class (it may include large parts of agricultural bare soil) and is only marked during post-editing where it is correct. Class 3 contains with a high reliability commission errors of 2006. These areas were mainly bare soil or sparsely vegetated in Image 2006 and therefore erroneously included in the built-up area, whereas in Image 2009 they are clearly vegetated and without built-up structures.

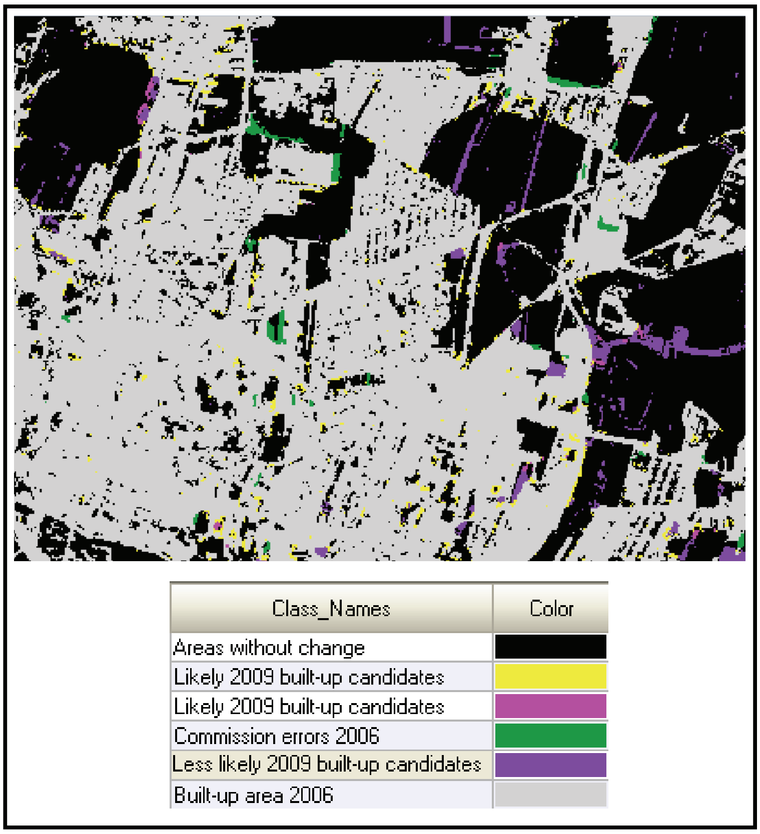


Figure 4. Automatically derived built-up change candidates in Vienna

3. Discussion and Conclusions

The update of the European Built-up and Imperviousness Layer for 2009 is an ambitious mapping activity within the FP7 geoland2 project with a very large dimension, very variable urban and climatic environments, and the typical constraints of many remote sensing projects. It requires a high degree of automation and automatically derived results with high initial precision in order to give enough way to the wall to wall visual control of the latter. As first update of the FTSP 2006 built-up and sealing layer, it is not only an update project, but actually to a large part also an "improvement" project. The update methodology of both, the built-up area and the degrees of imperviousness is entirely based on thresholding techniques using calibrated NDVIs and their 2006-2009 differences. NDVI calibration is directly related to the ISA degrees 2006 and avoids EO input data normalization and radiometric correction, though limited tests are performed with atmospherically corrected data as well. The latter however is no substitution for the performed calibration of the NDVI, but it may improve the radiometric relation of the red and the NIR bands. The update method is repeatable and can be re-applied to further updates in the future.

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