Sentinel-1 for Urban Areas
Comparison between Automatically Derived Settlement Layers from Sentinel-1 Data and Copernicus High Resolution Information Layers

Arthur Lehner[1,2], Vahid Naeimi[3] and Klaus Steinnocher[1]

[1]*AIT – Austrian Institute of Technology, Energy Department, Giefinggasse 2, 1210 Vienna, Austria*

[2]*Department of Geoinformatics –Z_GIS, University of Salzburg, Schillerstraße 30, 5020 Salzburg, Austria*

[3]*Department of Geodesy and Geoinformation, Vienna University of Technology, Research Group Remote Sensing E120.1, Gußhausstraße 27–29, 1040 Vienna, Austria*

Keywords: Remote Sensing, Sentinel-1, Impervious Surface, Copernicus.

Abstract: This work deals with the development of automatically derived settlement layers from Sentinel-1 data. The produced layers allow differentiation between built-up and non-built-up area. The results are visually compared with a standardized product of the Copernicus earth observation program, the Copernicus High Resolution Layer Imperviousness Degree. For evaluation of the accuracy, the European Settlement Map 2016 was chosen as a reference data set. In this study the ISODATA unsupervised classification algorithm is used for generating two layers that allow differentiation between built-up and non-built up area. The results reveal the suitability of Sentinel-1 data for urban areas mapping. The quality of the produced settlement layers are comparable to standardized products that are based on data from optical sensors e.g. Copernicus High Resolution Layer Imperviousness Degree or European Settlement Map 2016 respectively.

1 INTRODUCTION

Land monitoring within Europe and the European Union based on Earth Observation systems is fundamental regarding its scientficial, cultural and environmental impacts. With the agreement in 1985 to produce the first CORINE (EEA, 2000) land cover (CLC), the foundation for a European land monitoring program was laid. The programme maintains a number of databases including an inventory of land cover\land use (LCLU), produced operationally for most areas of Europe on a 6 to 10 year cycle (Ben-Asher, 2013). The CLC program later was incoporated in the European earth observation program “Copernicus”. Founded in the year 1998, Copernicus, previously known as GMES (Global Monitoring for Environment and Security), represents the European Programme for the establishment of a European capacity for Earth Observation.

Pan-European High Resolution Layers (HRLs) provide information on specific land cover characteristics, and are complementary to LCLU mapping such as in the CORINE land cover (CLC) datasets. The HRLs are generated from 20 m resolution satellite imagery through a combination of automatic processing and interactive rule based classification (Sannier et al., 2016). Out of five layer themes, the imperviousness layer presents the degree of sealed soil as it captures the spatial distribution of artificially sealed areas, including the level of sealing of the soil per area unit. The layer represents in this way a base map for various fields of research (Ciobotaru et al., 2016; Lefebvre et al., 2015; Mücher et al., 2015). Different applications using the Copernicus Imperviousness Layer (Hennig et al., 2015; Steinnocher et al., 2011) reveal its basic necessity and usability.

Another available data product is the European Settlement Map (ESM) 2016 that represents percentage of built-up area coverage per spatial unit using SPOT5 and SPOT6 satellite imagery from the year 2012 (European Commission, 2017). The ESM is a map expressing the proportion of the pixel area covered by buildings, and it was produced in 2013/2014 (Florczyk et al., 2016). In addition to these developments, the European commission recently announced the provision of an information layer on built-up presence. This information layer will be

Lehner, A., Naeimi, V. and Steinnocher, K.
Sentinel-1 for Urban Areas - Comparison between Automatically Derived Settlement Layers from Sentinel-1 Data and Copernicus High Resolution Information Layers.
DOI: 10.5220/0006320800430049
In *Proceedings of the 3rd International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2017)*, pages 43-49
ISBN: 978-989-758-252-3
Copyright © 2017 by SCITEPRESS – Science and Technology Publications, Lda. All rights reserved

derived from Sentinel-1 image collections (2016) and resolution will be about 20 meters. Since these data has not been available yet, it could not be considered for a visual comparison nor an accuracy assessment in this study.

By launching the Sentinel mission in 2014, the European Space agency ESA aimed to satisfy the need of the Copernicus program. Sentinel-1 is the first of five missions that ESA developed for the Copernicus initiative. Sentinel-1 comprises a constellation of two polar-orbiting satellites (Sentinel-1A, Sentinel-1B), operating day and night performing C-band synthetic aperture radar imaging, enabling them to acquire imagery regardless of weather conditions or light conditions (D'Aria et al., 2016).

This work presents the comparison of Sentinel-1 data used for the development of two automatically derived settlement layers differentiating between built-up and non-built up area and the Copernicus high-resolution layer 'Imperviousness Degree' and the European Settlement Map (ESM) 2016. In contrast to CLC data that are confined for Europe, satellites of the Sentinel mission collect data globally. The Sentinel-1 data coverage makes it possible to establish a global settlement layer.

2 DATA

This study uses Sentinel-1 image data, collected from the first 7 months of the year 2016, the Compernicus HRL imperviousness for the year 2012 and European Settlement Map 2016. Additionally a Sentinel-2A scene (date of acquisition: 02.07.2016) is used for visual interpretation of the results.

2.1 Sentinel-1 Data

The Sentinel program is the most comprehensive and ambitious European Earth Observation program. The Sentinel satellites provide unique operational sensing capabilities across the whole measurement spectrum, covering a broad range of applications. Thanks to their advanced sensing concepts and outstanding spatio-temporal sampling characteristics, the Sentinel satellites will collect more data than any earth observation program before (Attema et al., 2007). The first of the Sentinel satellite series, Sentinel-1A was launched on 3 April 2014. Seninel-1 (S-1) is a Synthetic Aperture Radar (SAR) mission for ocean and land monitoring. S-1 is the continuity mission to the SAR instruments flown on board of ERS and ENVISAT. The S-1 mission is implemented through a constellation of two satellites. The S-1B was launched on 25 April 2016. The S-1 data over the land masses are mainly acquired in Interferometric Wide swath (IW) mode. The S-1 Level-1 Ground Range Detected (GRD) products, which are suitable for the most of the land applications, consist of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model such as WGS84. The IW GRD products are provided in two High (20 m x 22 m) and Medium (88 m x 87 m) spatial resolutions resampled to 10 m and 40 m pixel spacing grids respectively (European Space Agency, 2013, p. 1).

Despite all corrections from Level-0 up to Level-1 data, the GRD data still need to be processed further before generating level-2 products. The S-1 Level-1 GRD data used in this study were pre-processed using the TU Wien SAR Geophysical Retrieval Toolbox (SGRT) (Naeimi et al., 2016). The pre-processing workflow include calibration, noise removal, georeferencing and terrain correction using a Digital Elevation Model (DEM), shadow mask generation, data conversions, and data resampling and tiling to a regular grid using an appropriate cartographic map projection. For the calibration, georeferencing and the terrain correction, the ESA's Sentinel-1 toolbox (S1TBX) is employed. The S1TBX operators are called via SGRT to perform the georeferencing using the S-1 precise orbit files provided externally by ESA. In this study the S1TBX Range Doppler algorithm and SRTM digital elevation data are used for terrain correction of the SAR scenes. After some further preprocessing steps like thermal noise removal, data format conversion and shadow mask generation the geocoded SAR scenes are resampled to the TU Wien Equi7 Grid. The TU Wien Equi7 Grid is designed to minimize the oversampling rate of the high resolution satellite data globally, while keeping its structure simple (Bauer-Marschallinger et al., 2014). After the pre-processing step, the S-1 backscatter time series were used to generate composites of monthly mean of backscatter for each polarization separately over the test site. In this study high resolution S-1 image stacks collected from 7 months (January – July) of the year 2016 are used.

2.2 Copernicus High Resolution Layer Imperviousness Degree

The HRL imperviousness is produced using an automatic algorithm based on calibrated NDVI. Similar to other HRLs of the Copernicus program, the imperviousness HRL is derived from 20 m resolution optical satellite imagery. The layer has 20 m geometric resolution and provides 101 classes of imperviousness while:

- 0: all non-impervious areas
- 1-100: imperviousness values
- 254: unclassifiable (no satellite image available, or clouds, shadows, or snow)
- 255: outside area (Langanke, 2013)

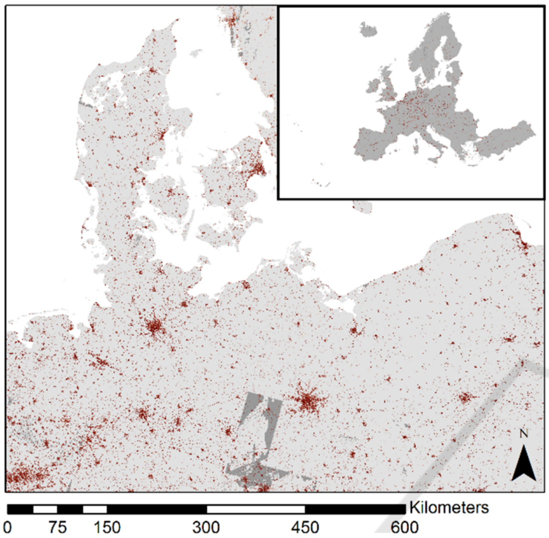

Figure 1: Coverage of the Copernicus HRL Imperviousness degree, red = impervious surface, grey = no satellite image available.

It is produced in a three years cycle and covers all 28 EU members (including United Kingdom) and 11 additional countries (Figure 1). The imperviousness layer contains two products: a 2012 status layer (degree of imperviousness 2012), as well as an imperviousness density change layer (2009-2012), based on the existing imperviousness product for 2009 (Langanke, 2013). In the presented study, we do not consider the imperviousness density change layer.

2.3 European Settlement Map 2016

The European Settlement Map is a spatial raster dataset with 10 meters resolution; an aggregated version with 100 meters resolution is also available. The ESM is mapping human settlements in Europe based on SPOT5 and SPOT6 satellite imagery from the year 2012. Similar to the Copernicus HRL it covers all 28 EU members (including United Kingdom) and 11 additional countries. For the ESM a 95% accuracy for the built-up class is stated (European Commission, 2017). Based on the accuracy and its other properties, the ESM was chosen as reference data for the accuracy assessment of the automatically derived settlement layer (S-1 USC II).

2.4 Study Area

The selected test site is the city of Vienna (coordinates: 48°12′N 16°22′E), the capital of Austria. The terrain ranges from hilly in the west to flat in the east of the city. Forest areas predominate the west and agricultural areas are mainly found in the east and southeast. The urban spectrum ranges from single-family houses to high-rise buildings, covers green houses and industrial areas.

3 METHODOLOGY

The objective of this study is to automatically derive two settlement layers using Sentinel-1 image stacks. The chosen method for this study is the ISODATA unsupervised classification algorithm. The ISODATA unsupervised classification algorithm clusters many-variable data around points in the data's original high- dimensional space and by doing so provides a description of the data (Ball and Hall, 1965). In other words, the cluster analysis groups data into objects – in our case pixel values – based only on information found in the data that describes the objects and their relationships. The objective is that the pixel values within a group be similar (or related) to one another and different from (or unrelated to) the pixel values in other groups. The greater the similarity (or homogeneity) within a group and the greater the difference between groups, the better or more distinct the clustering (Tan, 2006). In our case, a complete clustering is performed since every pixel value is assigned to a cluster.

The ISODATA unsupervised classification is performed on a single image composite representing the monthly mean of backscatter for a particular polarization. Parameters used for the unsupervised classification were:

- no. of iterations: 20,
- max. no. of clusters: 100,
- initial no. of clusters: 10,
- min. cluster size: 10 pixels.

This procedure is repeated for a stack of 5, 9 and 17 S-1 image composites. A final ISODATA unsupervised classification is performed again on 17 S-1 image composites but changing the number of iterations from 20 to 80 (S-1 USC). The result of the classification/clustering does not lead to the creation of a layer consisting of two classes, e.g. built-up and non-built-up area, but instead an image layer is created, where values correspond to a cluster ID. In this way all pixels having the same value belong to the same class/cluster (eCognition Developer 9.2, 2016).

This allows distinguishing of the pixels that have values with high variance (non-built-up) from those with low variance (built-up). Depending on the parameters and the input S-1 image composites, different numbers of clusters are generated. The resulting clustered pixels are visually assigned to classes “non-built up”, “impervious” and “built-up”.

The interim results are compared with each other and the classification results are compared with the Copernicus HRL Imperviousness degree of the year 2012. In order to classify and to quantitatively compare the results from the clustering process with the European Settlement Map 2016, a threshold is definded. A Multi-Threshold Segmentation algorithm is chosen to split the domain based on pixel values (eCognition Developer 9.2, 2016). Image objects are created and classified as “built-up”- and “non-built-up” area respectively (Figure 6). A final layer (S-1 USC II) is created. Further the ESM layer is aggregated to a 20 meters’ resolution. 500 points randomly distributed across the study area are used to assess the accuracy of the classes “built-up” and “non-built-up”. The authors are aware of the fact that the comparison of layers from different acquisition years can be seen critically. However, the areas that were selected for this study did not face severe changes over the last 10 years. Furthermore, changes in the buildings type (e.g. loft/attic conversion) within the urban landscape do not impact the comparison.

4 RESULTS

The objective of this research was to enhance the differentiation between built-up and non-built-up areas by including more S-1 image composites in the analysis (Figure 2). In Figure 2., steady values are represented by light gray while variant values are represented by dark gray values.

By adding more input S-1 images the separation between the built-up area class, impervious surface and non-built area become more visable. The ISODATA unsupervised classification (ICA) was performed on an image stack consisting of 17 S-1 data composites and resulted in a layer (S-1 USC) of 39 clusters (1-38). Each cluster was then assigned to a certain class (built-up, impervious surface, non-built-up) with a particular degree of imperviousness or perviousness respectively using an optical Sentinel-2A image as reference.

In Figure 3, the produced layer S-1 USC and the Copernicus HRL are visually compared. Figure 4 and Figure 5 allows the comparison of the ISO-Clustering results, the Copernicus HRL and the optical image from Sentinel-2A. The results of the Multi-Threshold Segmentation (S-1 USC II) are quantitatively compared with the European Settlement Map 2016 (European Commission, 2017) that was used as reference data. (Figure 6). The overall accuracy (OA) of the final layer (S-1 USC II) is 78,2% (Table 1).

Table 1: Accuracy Assessment (S1- USC II).

Classification	Non Built-up	Built-up	**Totals**
Non Built-up	272	69	341
Built-up	40	119	159
Totals	312	188	500
Producers Accuracy	87,2%	63,3%	**OA:** 78,2%
Users Accuracy	79,8%	74,8%	

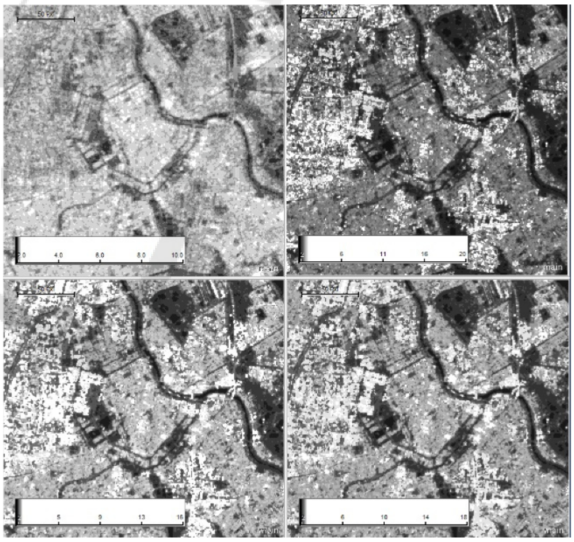

Figure 2: Increasing of the contrast between steady (light gray) and variant backscatter values (dark gray) by adding more layers to the analysis. a) ISODATA unsupervised classification (ICA) on 1 layer, polarization VH; b) ICA on 5 layers, mixed polarization (VH/VV); c) ICA on 9 layers, mixed polarization (VH/VV); d) ICA on 17 layers, mixed polarization (VH/VV).

5 DISCUSSION

The results from the ISODATA unsupervised classification reveal the possibility of mapping built-up areas. In the produced layer S-1 USC, different non-built up classes like urban parks, forest, cemeteries and other spacious vegetated areas are grouped and can particularly be distinguished from built-up areas. Agricultural fields are also related more acurately to non-built up areas, independent from their degree of vegetation cover. Furthermore, water bodies are classified as non-built-up areas independent from its amount of algae, depth, water quality or ground conditions. The "separation" between built-up and non-built up areas is improved by using more number of S-1 image composites.

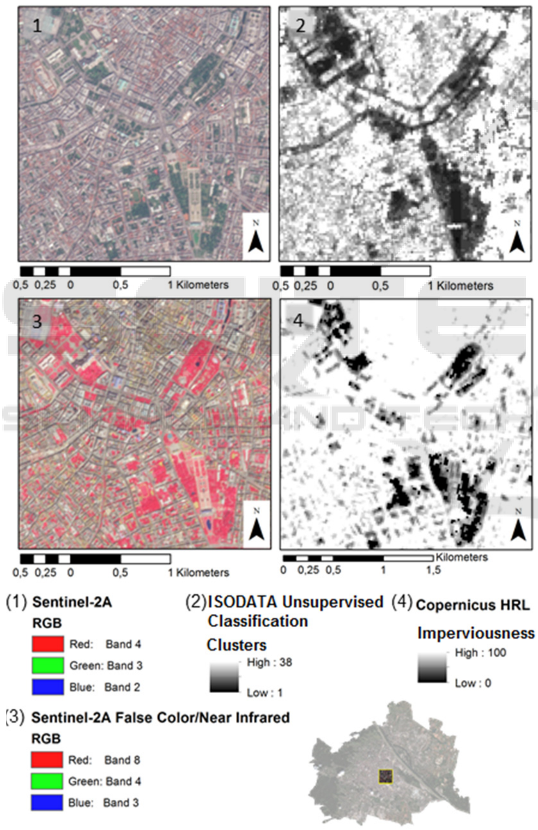

Figure 3: Visual comparison of S-1 USC and Copernicus HRL, Vienna, Austria 1) Sentinel-2A image, "true color" image, R (4) G (3) B (2), 2) S-1 USC, 3) "False Color/Near Infrared" image from Sentinel-2A, R (8) G (3) B (2), 4) Copernicus HRL.

In comparison to Copernicus HRL Imperviousness Degree, the produced layer S-1 USC shows generally a finer representation of the urban inventory. Green and (pervious) open spaces are visually easier to distinguish from built-up areas such as buildings, bridges and railroads (Figure 4, Figure 5).

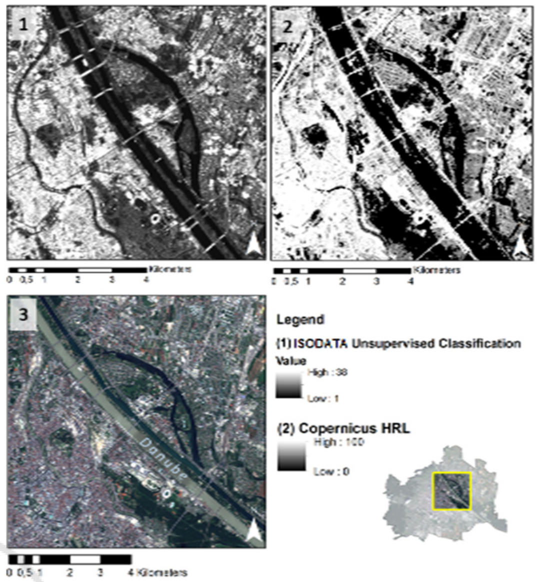

Figure 4: Danube River, Vienna, and crossing bridges depicted in (1) S-1 USC, (2) Copernicus HRL (some of the bridges captured by S-1 are missing in this image), (3) Sentinel-2A "true-color" image.

The shape of buildings appear sharper. The outlines of rivers and channels are more exact and bridges are depicted as built-up area in detail (Figure 5).

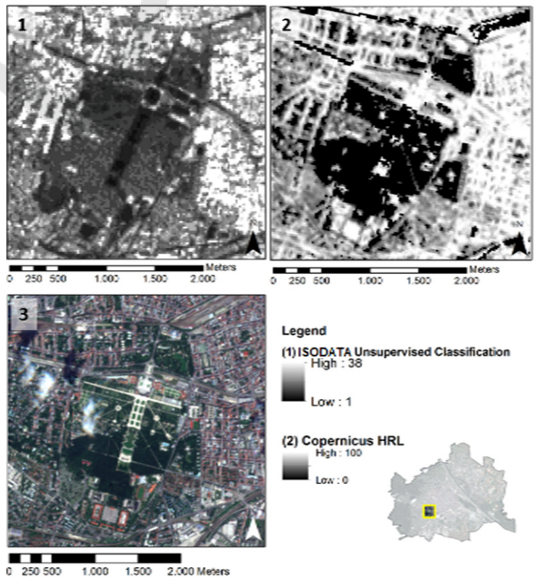

Figure 5: Schönbrunn palace and surrounding castle grounds (1) S-1 (2) Copernicus HRL (3) Sentinel-2A "true-color" image.

In comparison to European Settlement Map 2016, bridges crossing the Danube River are represented in the final produced layer S-1 USC II. Urban structures such as courtyards or street canyons are represented in greater detail within the ESM layer (Figure 6). This richness of detail leads back to fact that the ESM 2016 itself has a higher geometric resolution. The data set used for compiling the ESM 2016 has a higher geometric resolution (SPOT 5 and SPOT 6 data of 2.5m pixel size) and includes use of ancillary datasets (e.g. OpenStreetMap) (Florczyk et al., 2016).

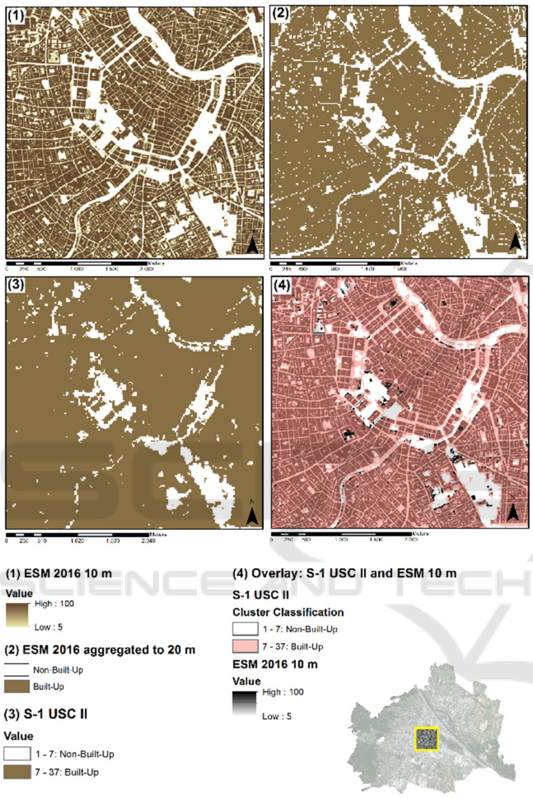

Figure 6: Vienna Downtown, Comparison of (1) ESM 2016, Copyright European Commission, European Settlement Map 2016, (2) ESM 2016 aggregated to 20 m and (3) S-1 USC II, (4) Overlay between ESM 2016 and S-1 USC II.

Although the results are overall promising, some challenges remain regarding the accuracy of the classification. High pixel values that indicate built-up area are found within forest areas, mainly in steep slopes. We attribute this to the fact that the backscatter measured by S-1 sensor is influenced by the terrain. Such areas with complex topography could be masked using a digital elevation model. Alternatively, the introduction of an object-based approach allows for defining certain areas as unsuitable for built-up area.

6 CONCLUSIONS

This study could demonstrate the value of Sentinel-1 data for mapping built-up areas. The preliminary results revealed that pixel based unsupervised classification of S-1 stacked backscatter composites allows to differentiate between built-up and non-built-up area within the urban landscape. The quality of the automatically derived settlement layers (S-1 USC and S-1 USC II) is comparable to standardized products based on optical sensors e.g. Copernicus HRL Imperviousness Degree or European Settlement Map 2016 respectively. The S-1 data available for this study were limited to a half year from 2016. Differentiation between built-up and non-built-up area based on the presented methodology can be enhanced by using more data covering the full year or multiple years.

The introduction of object-based methodologies where classification will not only depend on single pixel values but also on relation between objects may help to correct misclassifications. Certain terrain may be defined as inappropriate for built-up area or distance to other built-up area may be (more) relevant for classification. Finally, another proposal for a solution is the use of additional input data (composite monthly mean single band images) in order to enhance the differentiaton between built-up area (low variance) and non-built-up area (high variance).

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

REFERENCES

Attema, E., Bargellini, P., Edwards, P., Levrini, G., Lokas, S., Moeller, L., Rosich-Tell, B., Secchi, P., Torres, R., Davidson, M., 2007. Sentinel-1-the radar mission for GMES operational land and sea services. *ESA Bull. 131*, 10–17.

Ball, G.H., Hall, D.J., 1965. ISODATA, a novel method of data analysis and pattern classification. *DTIC Document*.

Bauer-Marschallinger, B., Sabel, D., Wagner, W., 2014. Optimisation of global grids for high-resolution remote sensing data. *Comput. Geosci. 72*, 84–93.

Ben-Asher, Z., 2013. HELM-Harmonised European Land Monitoring: *Findings and Recommendations of the HELM Project*. Tel-Aviv, Israel.

Ciobotaru, N., Laslo, L., Matei, M., Mușat, C., Lupei, T., Boboc, M., Deák, G., 2016. Mapping Romanian Wetlands – a Geographical Approach. Presented at the Conference: *3rd International Conference Water resources and wetlands*, Tulcea, Romania, p. 14.

D'Aria, D., Piantanida, R., Valentino, A., Riva, D., 2016. Freesar, an innovative SAR data processing framework, in: *Geoscience and Remote Sensing Symposium*

(IGARSS), 2016 IEEE International. IEEE, pp. 1214–1216.
eCognition Developer 9.2, T., 2016. eCognition® Developer Version 9.2.1 Reference Book.
EEA, E.E.A., 2000. Corine Land Cover. Eur. Environ. *Agency Cph. 163*.
European Commission, E. S. M. 2016 (2017) 'European Settlement Map'. Copernicus. Available at: http://land.copernicus.eu/pan-european/GHSL/EU%20GHSL%202014. Copyright European Commission, European Settlement Map 2016
European Space Agency, 2013. Sentinel-1 User Handbook, GMES-S1OP-EOPG-TN-13-0001, https://sentinel.esa.int/.
Florczyk, A.J., Ferri, S., Syrris, V., Kemper, T., Halkia, M., Soille, P., Pesaresi, M., 2016. A new european settlement map from optical remotely sensed data. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 9*, 1978–1992.
Hennig, E.I., Schwick, C., Soukup, T., Orlitová, E., Kienast, F., Jaeger, J.A., 2015. Multi-scale analysis of urban sprawl in Europe: Towards a European de-sprawling strategy. *Land Use Policy 49*, 483–498.
Langanke, T., 2013. GIO land (GMES/Copernicus initial operations land) High Resolution Layers (HRLs) – summary of product specifications, version 7 of 2013-10-14, *European Environment Agency, GIO land team at the EEA*, 2013.
Lefebvre, A., Picand, P.-A., Sannier, C., 2015. Mapping tree cover in European cities: comparison of classification algorithms for an operational production framework, in: *2015 Joint Urban Remote Sensing Event (JURSE). IEEE*, pp. 1–4.
Mücher, C.A., Hennekens, S.M., Schaminee, J.H.J., Halada, L., Halabuk, A., 2015. Modelling the spatial distribution of EUNIS forest habitats based on vegetation relevés and Copernicus HRL. *European Topic Centre Biological Diversity*.
Naeimi, V., Elefante, S., Cao, S., Wagner, W., Dostalova, A., Bauer-Marschallinger, B., 2016. Geophysical parameters retrieval from sentinel-1 SAR data: a case study for high performance computing at EODC, in: *Proceedings of the 24th High Performance Computing Symposium. Society for Computer Simulation International,* p. 10.
Sannier, C., Gallego, J., Dahmer, J., Smith, G., Dufourmont, H., Pennec, A., 2016. Validation of Copernicus high resolution layer on imperviousness degree for 2006, 2009 and 2012, in: P*roceedings of the International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences*, Montpellier, France. pp. 5–8.
Steinnocher, K., Köstl, M., Weichselbaum, J., 2011. Grid-based population and land take trend indicators–new approaches introduced by the geoland2 core Information Service for Spatial Planning, in: *NTTS Conference,* Brussels.
Tan, P.-N., 2006. Introduction to data mining. *Pearson Education India*.