THE GLOBAL URBAN FOOTPRINT - PROCESSING STATUS AND CROSS COMPARISON TO EXISTING HUMAN SETTLEMENT PRODUCTS

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ABSTRACT

The main goal of the TanDEM-X mission (TDM) is the generation of a global digital elevation model (DEM). The global SAR dataset, which is made available in the context of the TDM, is also used to create a global human settlement layer, the Global Urban Footprint (GUF). This paper presents a first large area cross comparison between the Global Urban Footprint and existing human settlement products, which shows promising results with an achieved confidence of 95.86% Overall, 71.15% Producer's and 85.22% User's accuracy.

Index Terms— global human settlement layer, urban remote sensing, classification, accuracy assessment

1. INTRODUCTION

Since the beginning of the 21st century the number of urban residents has exceeded the rural population for the first time in history. To gain understanding of the dynamics of rapid urbanization processes mapping of the urban and peri-urban development has gained more and more importance and is urgently needed. Spaceborne earth observation (EO) has successfully been established as a technology to provide global and up-to date geo-information on the distribution and development of human settlements [1]. One example for such an EO mission is the TDM, which acquires two global coverages of VHR SAR data within a period of one year with a resolution of three meter [2]. It is therefore predestined to be applied for global mapping purposes.
Accordingly, the German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR) has developed an image processing system to delineate built-up areas from the global dataset of the TDM. The main goal of this project is to derive a unique inventory of human settlement - the so called Global Urban Footprint (GUF). This paper presents a first large area cross comparison between the Global Urban Footprint and existing human settlement products to give a first impression of the quality of this unique data set.

2. URBAN FOOTPRINT CLASSIFICATION

The classification approach is based on a methodology, already published in [3] and [4]. In short, to delineate built-up areas from TanDEM-X Stripmap data, a texture measure (Speckle Divergence) is calculated using one Single Look Complex image with HH polarization. The classification procedure itself focuses on the combined analysis of local backscattering characteristics (amplitude) and local image heterogeneity (texture) to automatically derive a binary settlement layer (built-up, non-built-up). Pixels exhibiting high values for the amplitude image and speckle divergence are associated with built-up structures, whereas lower values correspond to non-urbanized area. Therefore the algorithm is sensitive towards the detection of man-made structures showing a vertical dimension. Dark areas in both the amplitude and texture are classified as non-urban.
The processing itself includes three main processing stages dedicated to the extraction of texture information, the generation of a binary settlement layer and a final post-editing and mosaicking phase.
The Urban Footprint Processor was successfully implemented to the TDM DEM processing chain in 2011. Since June 2014 the second processing stage was accomplished and one global coverage of Urban Footprint classifications was successfully derived from 180.000 TDM input images. The processing includes two types of products: One high resolution product of about 12m and a product with medium resolution of about 75m.

3. METHODOLOGY FOR CROSS-COMPARISON

Goal of this study is to analyze and compare the characteristics of the GUF to other existing human settlement products. Thereby we choose five different reference data sets, the European Urban Atlas (EUA), European Soil Sealing (ESS), a reference buildings layer, the urban class of MODIS500 and the urban class of GlobCover2009. These layers are explained in more detail in the next chapter.
First, we compare the GUF to highly detailed information, of the EUA for the city of Munich. As the Urban Atlas is only available for city regions bigger than 100.000

inhabitants, we compare the GUF also on a large area basis for entire Germany to all other products.
For the comparison we use the standard techniques for error matrix and kappa coefficient. The measurements are calculated based on every single pixel of the particular test area instead of randomly distributed check points.

3. STUDY AREA AND REFERENCE DATA SETS

3.1. STUDY AREA

For this study we use the first GUF mosaic of entire Germany, which is derived from about 500 single input scenes and which covers an area of 357.168 km². Fig. 1 shows a subset of the GUF product for the city of Munich, Germany. This subset as well as the full mosaic is compared to other products, described below.

3.2. REFERENCE LAYERS

3.1.1. European Urban Atlas (EUA)

The EUA is a free available high-resolution land use and land cover map, which is produced based on optical satellite images and which features an accuracy of 80% [5]. The EUA includes different thematic classes with a minimum mapping unit of 0.25 ha. Out of this we selected 9 urban classes, which include vertical built-up structures and which are presented in table 1. Fig. 2 shows the EUA in a binary representation for the city of Munich for the selected classes (S.L.: Degree of Soil Sealing).

Table 1: Selected classes of EUA

Code	Legend
11100	Continuous Urban fabric (S.L. > 80%)
11210	Discontinuous Dense Urban Fabric (S.L. 50% - 80%)
11220	Discontinuous Medium Density Urban Fabric (S.L. 30% - 50%)
11230	Discontinuous Low Density Urban Fabric (S.L. 10% - 30%)
11240	Discontinuous very low density urban fabric (S.L. < 10%)
12100	Industrial, commercial, public, military and private units
12230	Railways and associated land
11300	Isolated Structures

3.1.2 European Soil Sealing (ESS)

The ESS is a high resolution layer, covering entire Europe. It was derived by using high resolution satellite images of the IMAGE2006 database. The layer maps a continuous degree of soil sealing ranging from 0% to 100% with a geometric resolution of 20m. [6] gives an overall accuracy of 85%. The binary representation is derived by a simple thresholding for all values bigger than 0.

3.1.3 Reference Building Layer

The layer was derived by applying segmentation algorithms to the Rasterized Digital Topographic Map (DTK25) and by manual digitizing [7] and contains single buildings for entire Germany for the year 2008. Due to the fact that the GUF cannot depict the highly detailed geometry of single houses, the buildings layer was generalized by using a maximum filter with a window size of 5 x 5, which was applied to a 12m raster (Fig. 4).

3.1.4 MODIS500

The MODIS 500m map of global urban extent is the most accurate global human settlement layer, which is available so far [1]. It is provided by Boston University and the MODIS Land Group [8]. The urban class is defined as built environment, whereas a map of 2002 is used in this study and is shown in Fig. 5.

3.1.5. GlobCover 2009

GlobCover2009 is provided by Université catholique de Louvain UCL and ESA [9], whereas the urban class is defined as artificial surfaces and associated areas (Fig. 6). With a resolution of 300m the urban class of GlobCover 2009 is considered as global human settlement layer with highest resolution, which is available so far [1].

4. RESULTS

Compared to the EUA, the GUF shows high spatial correspondence. The Overall accuracy results in 94.60% (cp. Table 2) with a User's accuracy of 75.39%, a Producer's accuracy of 80.12% and a kappa coefficient of 0.746. The EUA is a classification of urban areas based on physical properties as well as functional land use. In contrast, the GUF is a classification of vertical man-made structures. Thus, functional thematic classes such as large parking lots are not detected in the GUF due to the respective data characteristics as well as the classification procedure. The relative comparison of both products is based on various definitions of urban areas, however, the spatial extents can be put in relation. The result reveals that spatial extents of both layers show significant agreement. This relation can by further analyzed by calculating the Producer's accuracy for every separate EUA sub-class.

Results are given in table 3. The GUF shows high concurrence in urban areas with thematic classes of high degrees of imperviousness. Producer's accuracy is decreasing when the degree of imperviousness is reduced. Best results are obtained for sub-class (11100, Continuous Urban fabric) in areas with a maximum degree of soil sealing, due to the fact, that this class includes downtown areas and the city center and thus a very high degree of vertical built-up structures.

Table 2: Cross Comparison between GUF and EUA

Overall [%]	User's Accuracy Urban [%]	Producer's Accuracy Urban [%]	Kappa
94.60	75.39	80.12	0.746

Table 3: Producers Accuracy of GUF and EUA

EUA sub-classes	Producer's Accuracy [%]
Continuous Urban fabric (S.L. > 80%)	97.79
Discontinuous Dense Urban Fabric (S.L. 50% - 80%)	91.97
Discontinuous Medium Density Urban Fabric (S.L.30% - 50%)	78.23
Discontinuous Low Density Urban Fabric (S.L. 10% - 30%)	52.67
Discontinuous very low density urban fabric (S.L. < 10%)	32.48
Industrial, commercial, public, military and private units	71.42
Railways and associated land	34.39
Isolated Structures	33.76

Table 4 summarizes the quantitative assessment between the GUF and the ESS for entire Germany. The accuracy is again quite high showing 95.73% overall, 63.98% User's, 81.01% Producer's accuracy and a kappa coefficient of 0.692. The most important difference between the ESS and the GUF is that sealed areas such as streets or parking lots are not included in the GUF product. This is due to streets or parking lots appearing as dark areas in the SAR image with low backscattering and low heterogeneity. These areas are classified as non-urban in the GUF.

Table 4: Cross Comparison between the GUF and the ESS

Overall [%]	User's Accuracy Urban [%]	Producer's Accuracy Urban [%]	Kappa
95.73	63.98	81.01	0.692

Comparison between the GUF and a generalized building layer shows highest confidence, which can be found in table 5, ranging from 95.86% Overall, 71.15% Producer's to 85.22% User's accuracy with a stable kappa coefficient of 0.753 for entire Germany. These results obtain a high quality of the GUF mosaic. Due to its resolution of 12m, city centers are classified very reliable as well as small villages.

Table 5: Cross Comparison between the GUF and a generalized Building Layer

Overall [%]	User's Accuracy Urban [%]	Producer's Accuracy Urban [%]	Kappa
95.86	85.22	71.15	0.753

Comparison between the GUF, MODIS500 and GlobCover2009 is outlined in table 6 and 7. Users's accuracy is quite low for both layers, indicating a high degree of over classification to both datasets, coming mainly from the fact, that all datasets show a totally different resolution ranging from 12m (GUF) to 300m (GlobeCover2009) and 500m (MODIS500). Nevertheless MODIS500 shows a higher confidence for User's accuracy (42.60%) and for kappa coefficient (0.398), whereas GlobeCover2009 shows a slight higher Overall accuracy (92.93%) and a higher Producer's accuracy (75.34%).

Table 6: Cross Comparison between the GUF and the Urban class of MODIS500

Overall [%]	User's Accuracy Urban [%]	Producers Accuracy Urban [%]	Kappa
91.13	42.60	46.85	0.398

Table 7: Cross Comparison between the GUF and the Urban class of GlobCover2009

Overall [%]	User's Accuracy Urban [%]	Producer's Accuracy Urban [%]	Kappa
92.93	24.10	75.34	0.338

5. CONCLUSIONS AND OUTLOOK

This paper presents a first relative comparison between the GUF and existing human settlement products showing high correspondence as well as deviations in certain areas – such as in low dense rural hinterlands. Therefore the GUF and the global DEM show also potential for interesting follow-on analyses in the urban context. These include the extraction of building structures and the estimation of building densities or modelling of building volume based on the DEM.

5. REFERENCES

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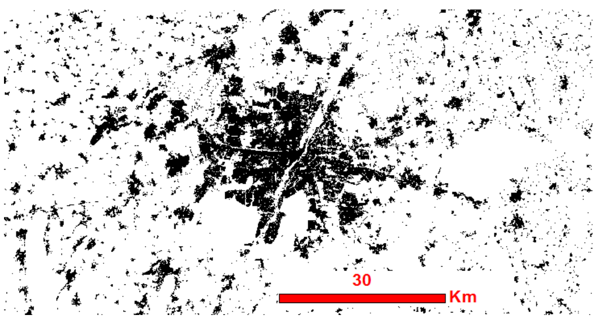

Fig 1: Global Urban Footprint for the city of Munich


Fig 2: Binary representation of European Urban Atlas

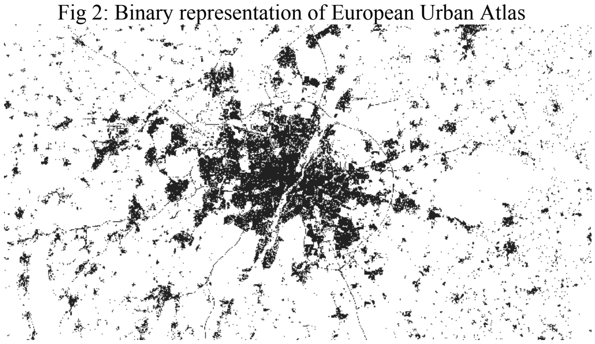
Fig 3: Binary representation of European Soil Sealing

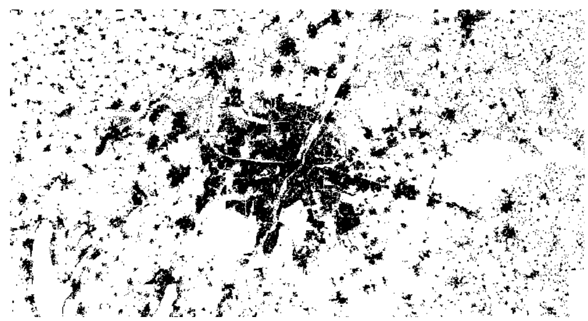
Fig 4: Generalized Building Layer

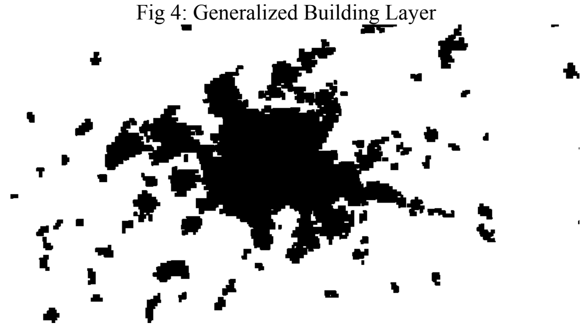
Fig 5: Urban class of Modis500

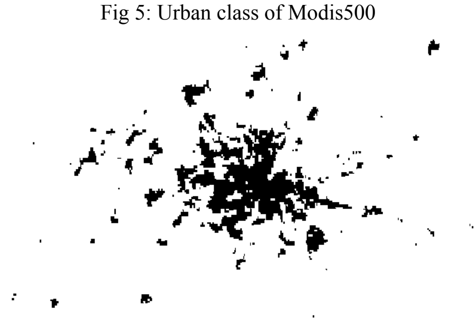
Fig 5: Urban class of GlobCover2009