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Accuracy assessment of the Copernicus Buildings Height 2012 layer based on the city of Warsaw

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Abstract: The techniques of converting stereo-pair aerial photographs or satellite images are used to prepare the digital surface models (DSM), digital elevation models (DEM) or to obtain the height of the objects. Recently, the Copernicus Land Monitoring service released a product presenting the building heights for the major – capital cities in Europe. The Building Height 2012 layer was derived based on the stereo images acquired by the IRS-5 satellite close to the defined reference year 2012. The main aim of the study was to examine the accuracy of the Copernicus Building Height 2012 layer in comparison with the building height derived from airborne laser scanning system. The study was carried out over the city of Warsaw (the capital of Poland). In general, data from both datasets are compatible, however the overestimation of the height was observed. The comparison carried out in two ways produced similar results. On average, the overestimation of the satellite-based building height for the study area reached 1.08 m.

Keywords: building height, Copernicus, satellite data, LIDAR, DEM, DSM

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1. Introduction

The accurate and up-to-date information on the building height is essential for effective spatial and urban planning. This information is widely used for the purpose of the research on urban microclimate, such as creating models of wind speed between high buildings, known as urban wind effect (Plate, 1999), or modeling the effect of the urban heat island (Droste et al., 2018). The scale and strength of these effects arise directly from the size and height of the city (Oke, 1967). The height of the buildings is also essential for assessing the shading effect, which affects not only the nearby flora, but also has impact on the well-being of residents leaving nearby. Higher buildings located in the small distance shorter the time of access to daylight per day in these buildings' neighborhood (Rehan, 2015). Knowledge of the height of buildings is also needed to determine the potential glide paths of the aircrafts to the airport located near the city (Paelinck, 1977).

Rapid development of the cities, increased the need for the accurate and up-to-date information on the building height obtained in a short period of time. This results in the development of advanced techniques of building height measurements. The basic measurement methods, including the measurement with the total station tachometer, did not allow to quickly obtain elevation data of many buildings. These methods are also very costly due to the involvement of a large number of field workers. The turning point was a rapid development of the modern LIDAR technology started with the invention of the laser in 1960 (Weitkamp, 2005). The LIDAR technique allows to quickly cover a large area with the point cloud, that are used to generate the Digital Surface Models (DSM) and Digital Elevation Model (DEM). Laser scanning is a technique that actively acquires a point cloud describing terrain coverage from the scanner placed on an airplane or drone. The scanning method is based on the laser signal distance measurement technique together with simultaneous measurement of the position and orientation of the sensor, which are most often obtained using the built-in GNSS receiver (Maas, 2002). Airborne laser scanning has quickly become a commonly used method for measuring the earth's surface. Thanks to its high resolution reaching even dozen points per 1 square meter of land, it allows spatial mapping of objects such as buildings with a precision up to 0.02 m (Hohle, 2013). However, among many advantages, this technique also has its disadvantage. The cost of obtaining data for a large area is still quite high, which includes not only the cost of the devices themselves and the planning of the flight, but also a large cost of data post-processing. Post processing includes filtering noises out from the raw data and then dozens of strips are combined into one consistent set, which is then subjected to time-consuming classification. Finally, combined and filtered points cloud can be processed into derivate products such as a Digital Surface Model (DSM) or Digital Elevation Model (DEM).

DSM and DEM can also be obtained from the satellite data, i.e. from SRTM or TanDEM-X satellite systems. The 90-metre TandDEM-X.DEM covers all of the Earth's land surface from 90°S and 90°N, totaling over 148 million square kilometers[1]. This 3D model of the Earth was completed in September 2016, being the first to capture the Earth with uniform accuracy and no gaps. Shuttle Radar Topography Mission (SRTM) is 30-meters resolution DEM data on near-globe scale from S to N[2] acquired within 10 days in February 2000 (Farr et al., 2007). The SRTM DEM pixel size is 30 m and its vertical accuracy is ±8 m (Elkhrachy, 2018).

Several studies used the satellite data acquired by TerraSAR-X satellite system[3]. However, this studies mainly focus on small-scale studies such as flood detection (Mason et al., 2010) or field monitoring (Koppe et al., 2013).

Another global terrain model developed in recent years is the ASTER Global Digital Elevation Model (ASTER GDEM). It covers 99% of the land surface with spatial resolution of 1 arcsec which is approximately 30 m. It has a declared accuracy better than 20 m (Bakuła, 2016). Another source of DTM is image matching of high-resolution satellite stereo images.

The other technology that allows for highly accurate digital elevation model generation is airborne laser scanning also known as LIDAR or ALS. This method, in contrast to satellite-based techniques, does not allow to quickly obtain elevation data of large area, however has a great advantage which is high accuracy. For example, DTM based on ALS technique has a resolution of 1 m and vertical accuracy of at least RMSE = 0.30 m (Kurczyński et al., 2013a).

In 2018, the European Environment Agency under the framework of the Copernicus program published the first large-scale map of buildings height for a major city in Europe. The building height 2012 layer (BH2012) is an additional dataset under the Copernicus Urban Atlas component. Urban Atlas is one of the local components of the European Copernicus Land Monitoring Service. Copernicus Land Monitoring Service contains five components related to mapping land cover and land use, monitoring biophysical parameters, monitoring specific area of interest, and providing imagery and reference data. One of the Copernicus specific areas of interest is focused on urban environment. The Urban Atlas component provides European wide comparable data on the land cover and land use for the year 2006, and 2012. In 2012, an additional Street Tree

[1] https://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10081/151_read-30139/#/gallery/32238, accessed: 01.2019.

[2] https://www2.jpl.nasa.gov/srtm/, accessed: 01.2019.

[3] https://earth.esa.int/web/eoportal/satellite-missions/t/terrasar-x, accessed: 01.2019.

Layer and changes 2006–2012 were produced and made available to the users. Recently, a BH2012 was added to the Urban Atlas portfolio. The BH2012 was derived using the stereo images acquired by the IRS-5 satellite system around the year 2012. The BH2012 is available freely for all cities that are the capitals of the European Union member states and the European Free Trade Association.

The aim of this study was to assess the accuracy of the Urban Atlas – Building Height 2012 against the national airborne laser scanning data. The study was focused on the city of Warsaw, the capital of Poland.

2. Study area

Warsaw is the capital of Poland, the country located centrally in Europe. Warsaw is a densely built city, with quite diverse density of build-up areas and height of the buildings. Ruined completely during World War II, it was initially rebuilt chaotically without any rules of spatial planning (Czyńska, 2018). In the 2000s, a certain order in spatial planning was only introduced, but there are still cases of constructing buildings disturbing the behavior of ventilation corridors (Osińska-Skotak and Zawalich, 2016).

The study area covers 532 square kilometers and it overlaps with the Warsaw administrative boundaries with inclusion of small nearby built-up areas. According to official statistics, Warsaw is inhabited by 1.744.351 people (as of 31.12.2018) and 3 391 per squired kilometre[4].

3. Data

3.1. Urban Atlas Building Height 2012

The BH2012 layer for Warsaw was downloaded from the Copernicus Programme website[5]. The BH2012 data is available for all capitals of the European Union member states and the European Free Trade Association. This layer was prepared using a Digital Terrain Model, the Digital Surface Model and the Normalized Digital Surface Model obtained through processing stereo-pair images of satellite images of the Indian IRS-P5 satellite[6].

The IRS-P5 satellite (also known as CartoSat-1) was placed in polar, sun-synchronous orbit, at an altitude of 6.185 km on 5 May 2005. It is equipped with two panchromatic cameras, the first of which is inclined with respect to the nadir by 26 degrees to the front of the orbit axis, and the other by 5 degrees to the rear of the orbit axis. This solution enables working in stereoscopic mode. The satellite covers the whole globe in a 126-day cycle, the bandwidth of the mapping is 30 km and the spatial resolution is 2.5 meters[7]. The wide swath of the IRS-P5 is beneficial for scanning a large area during one or few overpasses, obtaining ready-made altitude data.

The BH2012 layer is provided in the form of the Normalized Digital Surface Model, as a raster data (.tif format) with the spatial resolution of 10 m in the ETRS 1989 LAEA coordinate system. The building heights in the BH2012 are provided in meters, whereas the non-build-up areas have the zero value assigned.

3.2. Airborne laser scanning data (LIDAR)

Airborne laser scanning as an active technique for obtaining points cloud describing the land cover. The scanner is located on an airplane or drone. The scanning method is based on the measuring the distance the laser signal travels with the simultaneous measurement of the position and orientation of the sensor, which are most often obtained using the built-in GNSS receiver. The Head Office of Geodesy and Cartography (surveying and mapping agency in Poland) carried through the airborne laser scanning campaign during the period 2014–2015 (some data has been added after 2015) as a part of the IT System of the Country's Protection project (ISOK). As part of ISOK project, 92% of Poland was coved with laser points cloud with density of 4 pts/m^2 (12 pts/m^2 for urbanized areas) and accuracy reaching 0.2 m [8] [9]

[4] https://stat.gov.pl/obszary-tematyczne/ludnosc/ludnosc/powierzchnia-i-ludnosc-w-przekroju-terytorialnym-w-2017-r-,7,14.html, accessed: 01.2019.

[5] https://land.copernicus.eu/local/urban-atlas/building-height-2012, accesed 01.2019.

[6] https://land.copernicus.eu/local/urban-atlas/building-height-2012?tab=metadata , accesed: 01.2019.

[7] https://directory.eoportal.org/web/eoportal/satellite-missions/i/irs-p5, accesed: 01.2019.

[8] http://www.codgik.gov.pl/index.php/zasob/numeryczne-dane-wysokosciowe.html, accesed: 01.2019.

[9] http://www.isok.gov.pl/pl/, accessed: 01.2019.

(Kurczyński et al., 2013b). These data are available as LAS files classified into 9 classes, which numeration and names are specified by ASPRS (American Society of Photogrammetry and Remote Sensing). The assigned 9 classes refers to: 1) points created, never classified; 2) points lying on the ground; 3) points representing low vegetation, below 0.4 m; 4) points representing the average vegetation, in the range of 0.4–2.0 m; 5) points representing high vegetation above 2.0 m; 6) points representing buildings, structures and engineering objects; 7) noise; 8) points representing water areas; and 9) points from the multiple coverage areas.

3.3. Topographic Database (BDOT10k)

Topographic Database (BDOT10k) is a national digital topographic database in Poland containing the information about spatial topographic objects. The spatial resolution of this database corresponds to a topographical map in the scale of 1:10 000. BDOT10k was developed in years 2012–2013 and is consistently updated. Objects included in the BDOT10k are classified on three levels. The top level is represented by 9 subclasses, the second level by 57 subclasses, and the third by 286 subclasses. The data were obtained from the Head Office of Geodesy and Cartography in the GML format in the reference system ETRS89.

4. Methods

4.1. Data preprocessing

The BH2012 data was downloaded from the Copernicus website. The layer covering study area (Warsaw) is illustrated in Figure 1. The reference data: BDOT10k and LIDAR points cloud had to be pre-processed in order to be compared with the BH2012 layer. The "buildings, structures and devices" layers were extracted from the BDOT10k and used for further analysis.

Using the attribute "class" of the airborne laser scanning data (a points cloud with density of 12 pts/m^2) the cloud was divided into two separate classes – building and ground. These two classes were used to generate the DSM and DEM using the LASTOOL program dedicated for the processing of the LIDAR data. Points representing the ground class were processed into DTM, whereas points referring to

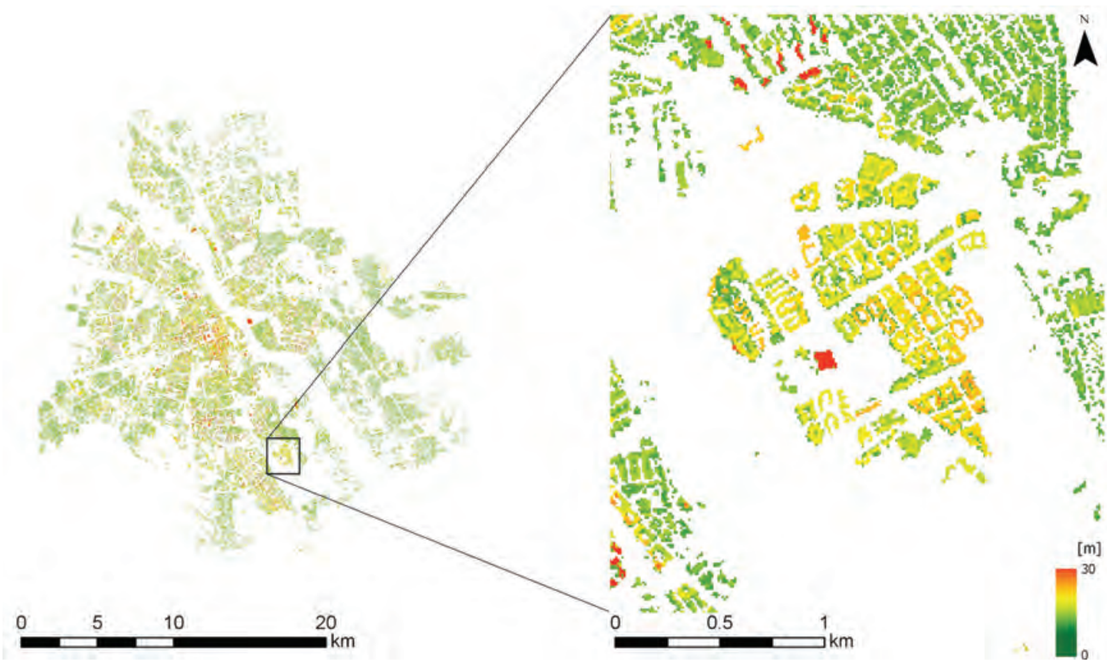

Fig. 1. Buildings height 2012 (BH2012) for Warsaw

buildings were combined with points from the ground class and processed into DSM. Obtained DSM has non-zero values only on buildings. Next, a normalized digital surface model (nDSM) was calculated by subtracting the DEM from DSM. The nDSM was resampled to a spatial resolution of 10 m to make the data comparable with the BH2012. Finally, the nDSM was clipped to the extent of the BH2012 layer.

First of all the correlation between both datasets at pixel level was analyzed. Secondly, the BH2012 was subtracted from the LIDAR-based nDSM map (Fig. 2).

To compare both products two, approaches were applied. Results of the subtraction were analyzed a) at the pixel level and b) taking into account the size of the buildings, to find out the discrepancy between these two datasets. For the purpose of both approaches, the buildings were classified according to the size into small with less or equal 9 pixels (900 m^2) – class 1, middle size between 9 and 20 pixels (900–20000 m^2) – class 2 and large with more than 20 pixels (above 20000 m^2) – class 3. Within each building class, the statistics such as mean and standard deviation were calculated and pixel distribution and scatterplots were prepared. In addition to that the analyses considering the building size were performed for all pixels within the class and for the average values calculate for each building separately. Using the previously obtained pixel group classes, each group was processed into a separate polygon. Two additional attributes were assigned to each of the polygons – the mean height for each building from the BH2012 map and from the LIDAR data map. These heights were calculated as the arithmetic mean of the values of pixels in range of each polygon.

To avoid the edge effect, the mixed pixels, not fully overlapped with the 'buildings' roofs were excluded from the analysis (Fig. 3). Before this operation, the describe statistic were also counted for pixels that not only fully cover building but also intersect with them to compare with further results. The obtained results are: mean = 1.19 m, median = 0.18 m, standard deviation = 7.80 m, RMSE = 7.89 m.

This process reduced not only the edge effect but also eliminated the narrow structures with the width less than 10 m, e.g. viaducts, bridges.

Fig. 2. Subtraction of the Building Height 2012 layer from the LIDAR data

Geoinformation Issues
Vol. 10, No 1 (10), 53–64/2018

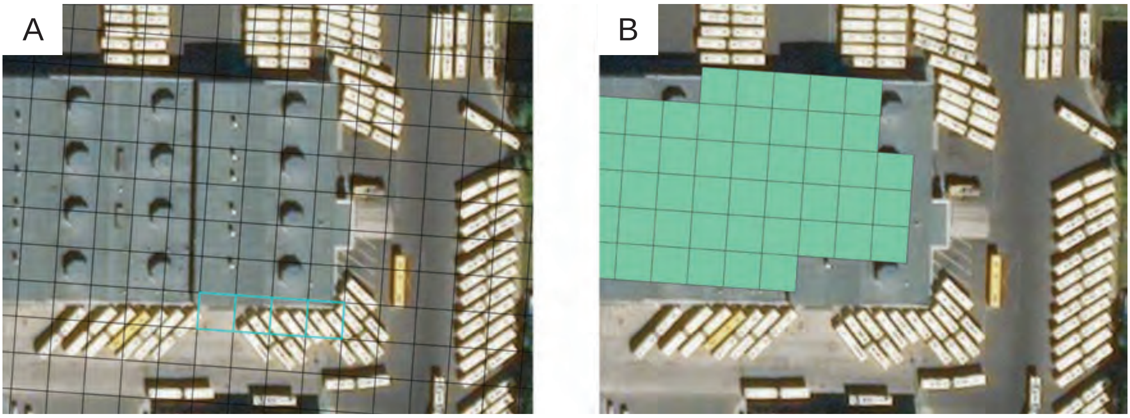

Fig. 3. Mixed pixels not fully overlapped with the building roof (A) and pixels (in green) extracted for further analysis (B)

5. Result and discussion

The correlation at the pixel level between the laser-based nDSM and BH2012 is presented in Figure 4. There is a linear correlation between both datasets (correlation coefficient for all data is 0.77), in particular for the pixels with the height less than 30 m (correlation coefficient calculated for these pixels is 0.67) despite the fact that the graph presents high concentration of outliers in the lower heights.

By contrast, there is lower correlation in the pixels with heights higher than 30 m (correlation coefficient equals 0.57). There is also a large number of outliers corresponding to various heights. The detailed analysis of the extreme outliers revealed that these values correspond to pixels located mainly on the edges of tall buildings such as skyscrapers or chimneys. In such cases, matching pixels has extremely different values, for example pixels located on the edge of a building have a high value in the BH2012 map, and low value in the LIDAR-based map (Fig. 5).

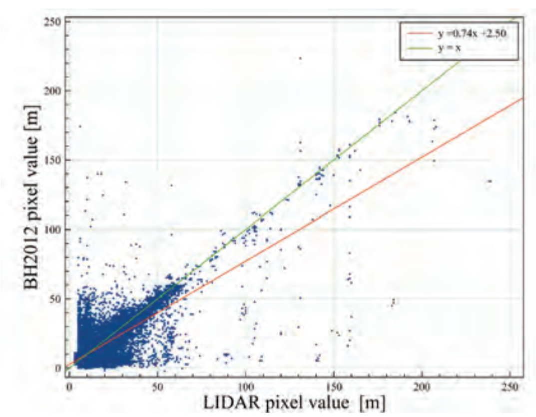

Fig. 4. Correlation between the value of pixel from the BH2012 layer and corresponding value of pixel from the LIDAR-based map

It is also noticeable that the greater concentration of outliers occurs above the trend line. These are pixels, which have a higher value on the BH2012 map compared to the data from LIDAR. The spatial distribution of the building heights derived based on two datasets is illustrated in Figure 6. The extent of the buildings obtained from the Topographic Database (BDOT10k) were shown as polygons with black outline. There is a visible edge effect on the BH2012 layer (Fig. 6A). Pixels that have a value different from 0 appear outside the building extent in places, where the distance between two buildings is around 2 pixels (20 metres). On the LIDAR-based map, the boundaries of the buildings are more pronounced, and the transition between "buildings" and "ground" pixels is easily readable (Fig. 6B). This is probably due to the classification of impervious surfaces around buildings as buildings and interpolation of heights between two or more close roofs in the BH2012 layer. This interpolation could have given worse results due to smaller pixel size of the LIDAR height map at the preprocessing stage.

The edge effect is less visible in case of a fairly large buildings (around 53 000 m^2), which is shown in Figure 6C and 6D. However, it has to be noticed

Fig. 5. The example of the outlier – the height of the chimney: B – based on BH2012 (three pixels) and C – based on the LIDAR data (two pixels) with the ortophoto basemap (A)

that buildings in the BH2012 layer are higher than in LIDAR-based map. The reverse situation is observed in case of a narrow buildings on the east of the large building (Fig. 6A and 6B).

The map of subtracted BH2012 from the LIDAR-based map is presented in Figure 2. The average pixel values in the subtracted map is equal to minus 1.08 m, a standard deviation of 8.42 m, which would indicate a systematic error, for example overestimation of the height of buildings in the BH2012 layer. For a more accurate analysis of the distribution of subtracted values, the results for the three building classes are presented in Table 1. Within these classes, statistics such as the mean and the standard deviation were examined.

It can be observed that with the increase of the building size, the standard deviation decreases from 8.7 m to 5.1 m for the Class 1 and Class 3, respectively. In class 1, the average height difference is equal to 0.7 m, whereas in classes 2 and 3 the average drops to -2 and -1.8 m, respectively. The highest deviation from 0 is observed in Class 2. Generally, these results indicate overestimation of the BH2012 data compare to the LIDAR data.

Comparing these results with previous ones calculated from the pixel values before extraction only a pixel that fully covers building (mean = 1.19 m, median = 0.18 m, standard deviation = 7.80 m, RMSE = 7.89 m) it can be observed that previous assumptions about the impact of “edge pixels” on the final result are true. These pixels in a significant way lower the accuracy of BH2012 because the values of these pixels in the BH2012 dataset are systematically lower than values of corresponding pixels in LIDAR dataset. It is connected with the smaller size of pixel in BH2012 map and potential geometrical shifts.

For each building size groups, the pixel frequency distribution and correlation between the BH2012 and LIDAR data (scatterplots) were illustrated in Figure 7. In general, the majority of pixels are located close to “0” values, which indicates quite good compatibility between both datasets. However, there are pixels with large discrepancies visible in each of the building classes. The scattering plots confirm a positive skewness coefficient of 0.11 and a median of –1.31 less than an average of –1.0.

Table 1. Statistics for classes of building size calculated based on the result of the subtraction of BH2012 and LIDAR data

Class name	Total area of grouped pixel [m^2]	Mean [m]	Standard deviation [m]	Median [m]	RMSE [m]	Population size (no of pixels per class)
Class 1 buildings with an area < 9 pixels	10–900	0.71	8.67	0.00	8.70	4017
Class 2 buildings with an area between 9–20 pixels	900–20 000	–2.04	8.94	–1.78	9.17	4748
Class 3 buildings with an area > 20 pixels	> 20 000	–1.80	5.06	–1.91	5.37	2938

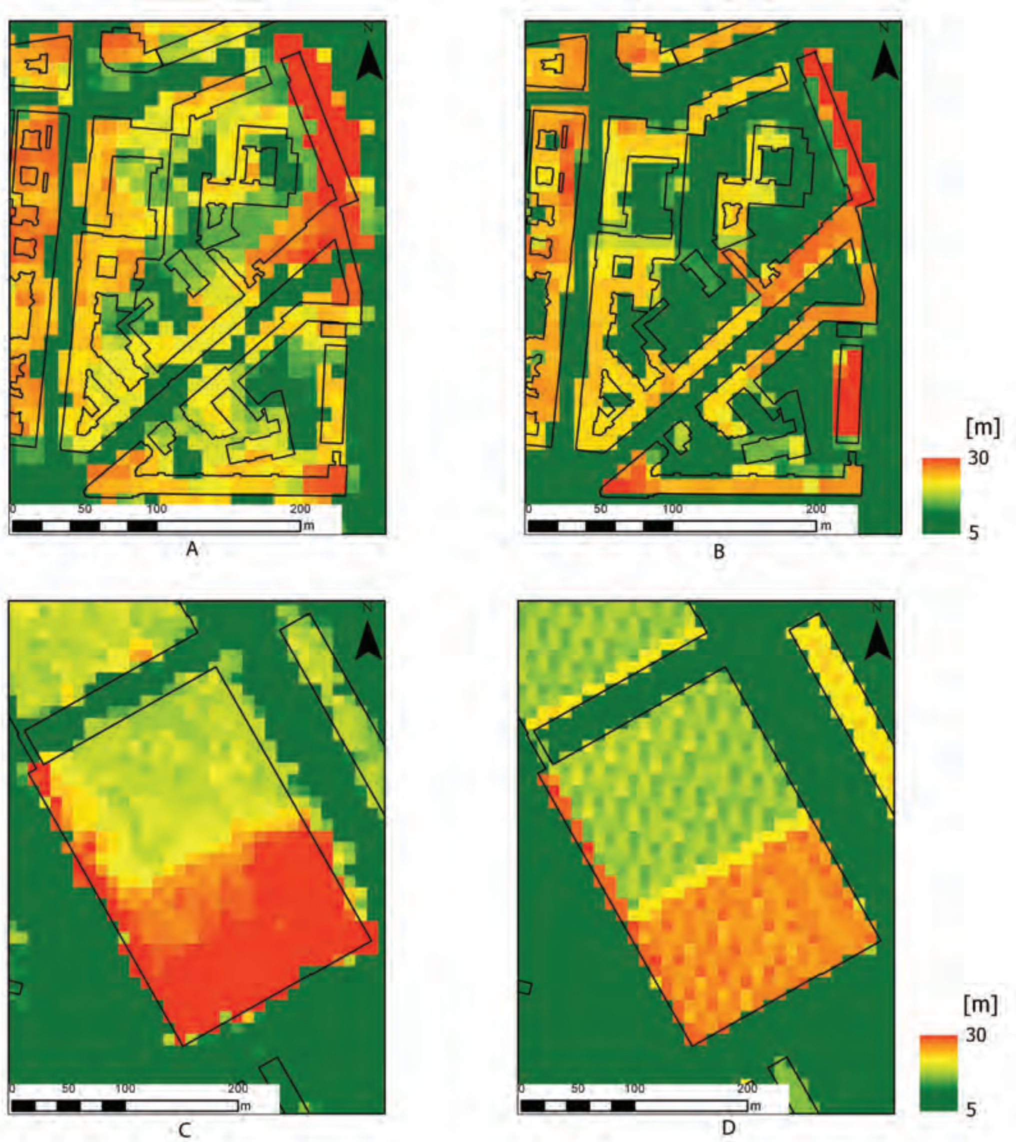

Fig. 6. Comparison of the building height derived from the BH2012 (left) and LIDAR data (right)

The pixel frequency distribution for individual building classes varies between classes. In the scatterplots presented in Figure 7 for Class 1 and 2, the visible trend is noticeable, but also the value on the left side of the symmetry axis of pixel frequency distribution graphs is noticeable, while, in Class 3, there is no visible trend.

Due to the fact that the comparison at the pixel level may be subject to error, because of the possible geometrical shifts of both datasets and different interpolation methods as well as different resolution, it was also decided to perform a comparison with another method. The height values from both datasets were averaged over the area of each building and compared to each other. Comparison obtained with this method is less sensitive to fluctuations in pixel values at roof edges. The results of the analysis of for Class 2 and 3 are shown in Figure 8.

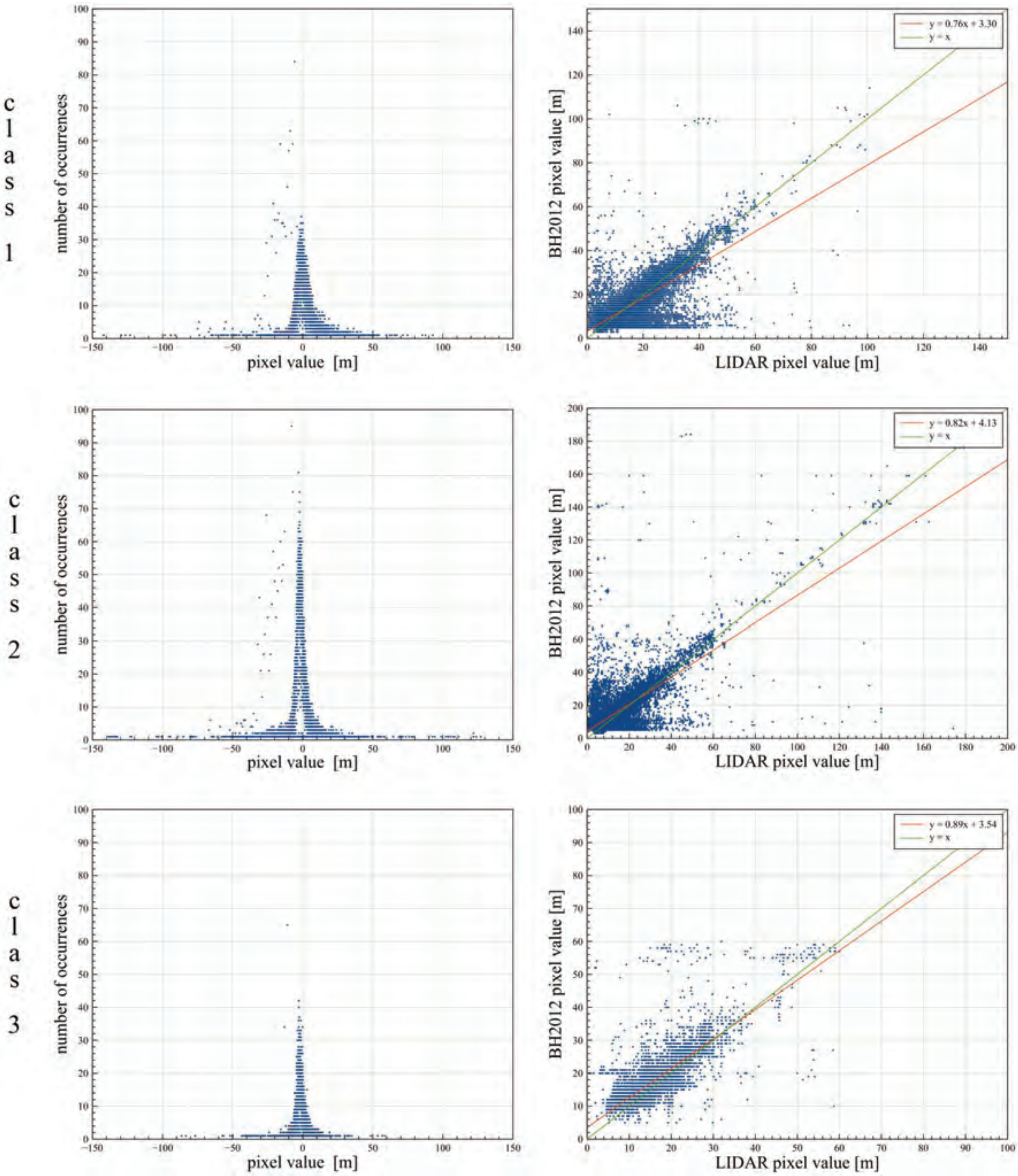

Fig. 7. Pixel frequency distribution for the subtracted map without 0 value being drawn (left) and the correlation between the BH2012 and LIDAR data (right) for each class of the building size

The average difference in the building heights for both datasets is 1.95 m for Class 2 and by 2.00 m for Class 3. As predicted, the visible linear trend is more noticeable with the averaged values than in the pixel to pixel comparison. There was also a significant decrease in number of outliers. The detailed analysis of the outliers showed that the some of the outliers are caused by different time between data

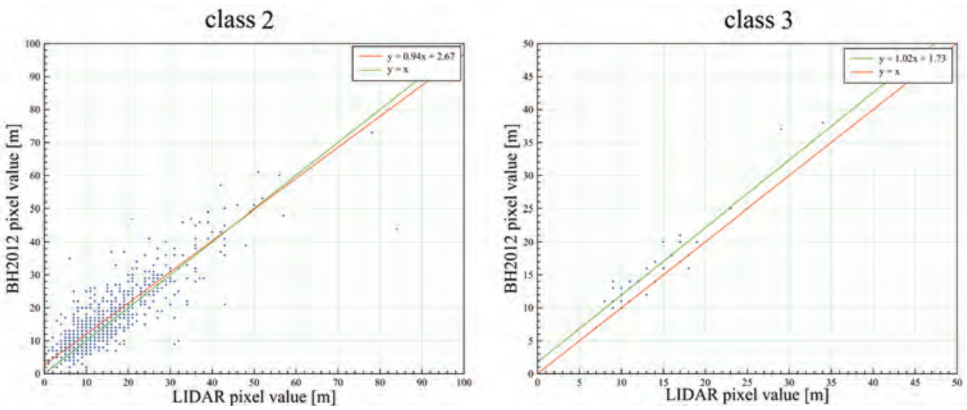

Fig. 8. Correlation of mean values of pixels located in single building

acquisition of BH2012 and LIDAR. Figure 9 presents the example of the building located at 2 Annopol Street in Warsaw, which existed on the BH2012 however, it was demolished before 2015 thus did not appear on the LIDAR data.

The accuracy of the BH 2012 varies amongst the building size classes. The larger the size of the building is, the more pixels are located in the area, giving a larger statistical sample, which in turn causes a decrease in the standard deviation. However, a comparison of the average pixel height for Class 3 in second comparation approach showed that the heights in the BH2012 layer differ only by 2 m on average compared to the reference height obtained from laser scanning data.

The analysis of the frequency of pixel values and correlation between the reference data and the BH2012 also confirmed the overestimation tendency. It has to be stressed, that the overestimation effect is also caused by date of the data acquisition. the LIDAR reference data was obtained 3 years later than the IRS-5 satellite data used to derived the BH2012. The 3-years difference results in new buildings being constructed or old building demolished. This is visible on the map of subtraction (Fig. 2) of both datasets as pixel with values above 0 and this would overestimate the total result. Therefore, it is reasonable to assume that the BH2012 map overestimates the height with a statistical error of overestimation of about –1.08 m.

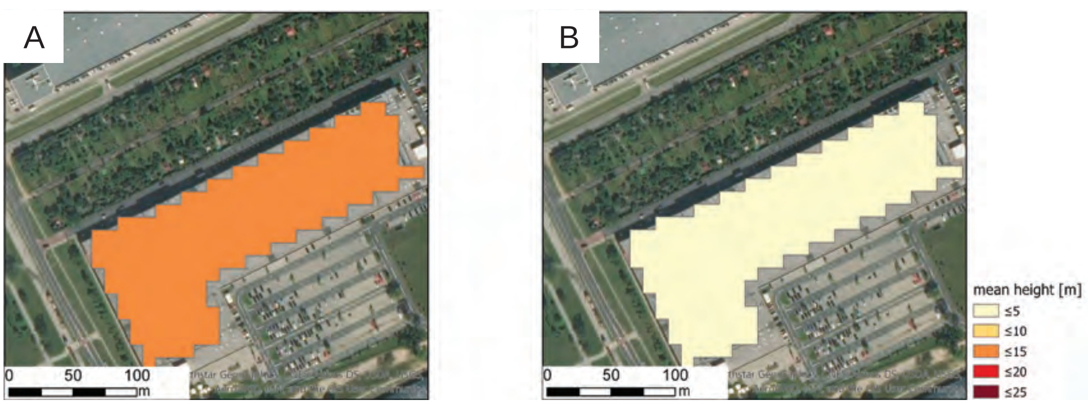

Fig. 9. Building located at 2 Annopol St. in Warsaw demolished between year 2012 and 2015. Mean height obtained from “Buildings height 2012” map (A) and from LIDAR data (B)

6. Summary

The Copernicus Building Height 2012 layer is the first attempt to map the height of buildings from the satellite system on such a large scale (all capitals of the European Union member states and the European Free Trade Association). The BH2012 layer is an additional product under the Copernicus Urban Atlas component. Urban Atlas is one of the local components of the European Copernicus Land Monitoring Service. This article presents the accuracy assessment of the BH2012 based on the reference airborne laser scanning data. On average, there is a quite good compatibility between two datasets, however there are areas or single pixels with large disagreement. The overestimation of the building high was observed in the BH2012 layer. These is partly caused by the difference in the date of the data acquisition. The LIDAR reference data was obtained 3 years later than the IRS-5 satellite data used to derived the BH2012. The 3-years difference results in a new building being constructed which after subtracting two datasets appeared as overestimation. In general, the airborne LIDAR points cloud with 12 pts/m^2 provide much more accurate and detailed information on the building height that the BH2012. Due to the pixel size of the BH2012 (10 × 10 m), the narrow buildings are not present and the non-build-up space even up to 20 m between buildings is not captured. If this layer becomes a cyclic Copernicus product carried out with similar accuracy, it can be successfully used for large-scale analyzes or creating models that do not require precision of level of decimeters. Despite its drawback, which is of lower accuracy than LIDAR data, these data have many advantages, among which there is easy and free access to the BH2012 data for all users. By contrast, the LIDAR data are not free for the commercial use and it requires the high computing power to process the clouds points.

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The LASTOOLS program of rapidlasso GmbH used for data preprocessing has been used in accordance with the research purposes in accordance with the provisions of the license

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Ocena dokładności warstwy Copernicus Building Height 2012 na przykładzie miasta Warszawa

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Streszczenie: Techniki przetworzenia stereopar zdjęć lotniczych lub obrazów satelitarnych wykorzystywane są do tworzenia numerycznych modeli terenu, numerycznych modeli pokrycia terenu czy generowania wysokości budynków. W 2018 r., w ramach europejskiego programu monitorowania powierzchni Ziemi – Copernicus Land Monitoring została udostępniona warstwa przedstawiająca wysokości budynków obejmująca zasięgiem wszystkie Europejskie stolice. Warstwa wysokości budynków została opracowana na podstawie analizy stereopar obrazów satelitarnych z satelity IRS-5, zarejestrowanych około roku 2012. Głównym celem prowadzonych analiz było wykonanie oceny jakościowej warstwy wysokości budynków Building Height 2012 w odniesieniu do krajowych danych referencyjnych, którymi są dane z lotniczego skaningu laserowego uzyskane w ramach projektu ISOK. Analizami objęto obszar miasta Warszawy. Wyniki analizy pokazują, że jest całkiem duża zgodność pomiędzy dwoma zbiorami danych, jednakże zaobserwowano także przeszacowanie wartości wysokości budynków. Obie metody porównania wykorzystane w tej pracy przyniosły podobne wyniki. Średnia wartość przeszacowania w wysokościach uzyskanych z danych satelitarnych wynosi 1.08 m

Słowa kluczowe: wysokość budynku, Copernicus, dane satelitarne, LIDAR, NMT, NMPT