Attachment 3b

SUMMARY OF PROFESSIONAL ACHIEVEMENTS

Dr inż. Agata Hościło

Institute of Geodesy and Cartography

Remote Sensing Centre

Warsaw, 2019

1. NAME AND SURNAME

Agata Hościło

2. DIPLOMAS AND DEGREES

18.12.2009	**Doctor** University of Leicester, Department of Geography, United Kingdom Doctoral thesis title: „Fire regime, vegetation dynamics and land cover changes in tropical peatland, Indonesia”.
21.12.2001	**Engineer** Warsaw University of Technology, Department of Geodesy and Cartography Faculty: Cadastre and Geographic Information System Engineer thesis title: “Management of road networks in Geographic Information System”.
12.01.1999	**Magister** University of Warsaw, Department of Geography and Regional Studies Faculty: Geo-ecology and Remote Sensing of Environment Master thesis title: “Land use changes in the Narew River National Park between 1956 and 1997”.

3. INFORMATION ON EMPLOYMENT IN RESEARCH AND SCIENTIFIC INSTITUTIONS

1.06.2014 – to date	Institute of Geodesy and Cartography, Remote Sensing Centre, Assistant Professor, Head of Remote Sensing of Natural Hazards Laboratory
1.10.2011 – 30.05.2014	Institute of Geodesy and Cartography, Remote Sensing Centre, Assistant Professor
1.05.2009 – 14.09.2011	University of Leicester, Department of Geography, United Kingdom Post-Doctoral Research Associate
1.04.2005 – 30.04.2009	University of Leicester, Department of Geography, United Kingdom PhD Student
10.05.2002 – 30.03.2005	Institute of Geodesy and Cartography, Department of Remote Sensing Researcher
1.11.1999 – 09.05.2002	Institute of Geodesy and Cartography, Department of Remote Sensing Geographer

4. SCIENTIFIC ACHIEVEMENT FORMING THE BASIS FOR THE HABILITATION PROCEDURE

4.1 Title of scientific achievement and monothematic cycle of publications

The scientific achievement forming the basis for the habilitation procedure under art. 16 item 2 of the Act of March 14, 2003 on Academic Degrees and Titles as well as Degrees and Titles in Arts (Journal of Laws No. 65, item 595, as amended) consists of a series of six original academic publications entitled:

Assessment of the usefulness of satellite remote sensing for determining the distribution and spatial diversity of forest and detection of forests changes

The scientific achievements forming the basis for the habilitation procedure have been included in the four articles in part "A" of the journals of the Ministry of Science and Higher Education (MNiSW) and two articles in part "B". The total impact factor of the scientific achievement (according to the score for the year of publication of the article) is equal **8,119**, while for my entire scientific career is equal **37,621**. The total number of points according to the Ministry of Science and Higher Education (according to the score for the year of publication of the article) for scientific achievement is **114**, while for my entire scientific career of **445**.

The results of the research comprising the scientific achievement have been published in the following articles (in order reflecting the progress of work):

P1: Hoscilo A., Balzter H., Bartholome E., Boschetti M., Brivio P.A., Brink A., Clerici M., Pekel J.F., **2015**, A conceptual model for assessing rainfall and vegetation trends in sub-Saharan Africa from satellite data. *International Journal of Climatology*, *35*, 3582-3592, doi:10.1002/joc.4231. **IF_{2015} = 3.609 / Pts $MNiSW_{2016}$ = 35**
I assess my contribution to this publication as equal 70%. I contributed to the development of the conceptual approach, data collecting and processing, preparation of scripts in the IDL programming language, analyzes, calculation of statistics and the writing of the first draft of the entire publication.

P2: Hoscilo A., Tomaszewska M., **2015**, CORINE Land Cover 2012 – 4^{th} CLC inventory completed in Poland, *Geoinformation Issues*, *no 1 (6), 49-58*. **Pts $MNiSW_{2016}$ = 7 (B)**
My contribution to this publication is equal to 90%. I was managing the project at all its stages, controlled the quality of the interpretation of land cover changes, analysed the result of the project, prepared tables and wrote the entire publication.

P3: Hościło A., Mirończuk A., Lewandowska A., **2016**, Determination of the actual forest area in Poland based on the available spatial datasets (Określenie rzeczywistej powierzchni lasów w Polsce na podstawie dostępnych danych przestrzennych). *Sylwan*, *160*, 627-634. **IF_{2016} = 0.481 / Pts $MNiSW_{2016}$ = 15**
My contribution to this publication is equal to 65%. I contributed to the preparation of a project, development of a method for determining the actual forest cover, including the concept of multi-source data integration, participated in the quality control of input data and final products, and publication preparation.

P4: Mirończuk A., **Hościło A**., **2017**, Mapping tree cover with Sentinel-2 data using the Support Vector Machine (SVM), *Geoinformation Issues*, vol. 9, no. 1(9), pp. 27-38. **Pts $MNiSW_{2016}$ = 7 (B)**

My contribution to this publication is equal to 50%. I contributed to the development of methodological concepts and assumptions, supervised the work, I was involved in the interpretation of results and preparation of the publication.

P5: Hoscilo A., Lewandowska A., **2019**, Mapping forest type and tree species on a regional scale using multi-temporal Sentinel-2 data. *Remote Sensing*, 11 (8), 929. **IF_{2019} = 3.406 / Pkt $MNiSW_{2016}$ = 35**
My contribution to this publication is equal to 70%. I contributed by obtaining and managing the project, developing a methodical concept, performing the classification of tree species, elaborating and interpreting the results, preparing the tables and figures presented in the publication and preparation of the entire publication.

P6: Hoscilo A., Lewandowska A., **2018**, Assessment of forest damage caused by the August 2017 hurricane using Sentiel−2 satellite data (Zastosowanie danych z satelity Sentinel−2 do szacowania rozmiaru szkód spowodowanych w lasach huraganowym wiatrem w sierpniu 2017 roku). *Sylwan*, *162*, 619-627. **IF_{2018} = 0.623 / Pts $MNiSW_{2018}$ = 15**
My contribution to this publication is equal to 80%. I was involved in the development of methodological concepts and assumptions performed a literature review, data analyses, interpretation of results and the preparation of the publication.

4.2 Description of the aims of the work, achieved results and possible use of the results

Introduction and national of the research

The monothematic cycle of six forming the basis for the habilitation procedure concerns an important and current problem of obtaining information on the real distribution and spatial diversity of forest and detection of changes in forests using advanced methods of satellite remote sensing.

Knowledge about the distribution and spatial diversity of forest and detection and monitoring of forest changes is important in the process of sustainable management of natural resources (Franklin, 2001; Naudts i in., 2016), assessment of actual forest cover at country level, in assessing the state of the natural environment, making the right decisions in crisis situations. It is also very important for correct reporting of national and international statistics, due to the international commitments under the Climate Convention and the Kyoto Protocol to determine the forest carbon content, emission assessment and CO_2 sequestration capabilities (IPCC, 2018; UNFCCC, 2008).

Researchers dealing with the analysis of the carbon balance taking into account land cover and land use changes, pointed out the lack of the accurate information on: a) spatial distribution and forest diversity, b) direction of real forest changes, often statistical data contains information about the area of changes without information on the direction of the forest change, c) limited data on areas subject to natural succession, which are often omitted in statistics on changes over the non-forest areas (Houghton et al., 2012).

In many countries, including Poland, the forest area and assessment of the forest condition are determined on the basis of traditional field based inventory of forest. The limitation of this approach is the lack of accurate information on the spatial distribution and variability of forest within the forest or administration units (e.g. forest stands, compartments, districts). In Poland, forests occupy 29.5% of the country's area (GUS, 2017), of which 77% of forests are managed by the State Forests State Forest Holding, 19.2% are private forests, the remaining forests belong to national parks (2%), communes, other ownership of the State Treasury (1% each) (CILP, 2017). The State Forests are managed according to the forest management plans, which are updated every 10 years, using the traditional sampling methods and taking into account the goal of having a sustainable forest economy. The forest inventory data are well recorded, aggregated to the stand level, and stored in the National Forest Database. In contrast, the privately owned forest is not that well inventoried or recognised. According to the law (Forest Act. of 28 September 1991), the governor acts as the controlling body for the private owners. The major problems identified around the management of the privately-owned forest are i) a lack of any or up-to-date simplified forest management plans and inventory data, ii) disagreement about the forest status between on the ground and official cadastral records, iii) lack of up-to-date information on the forest extent and high cost of the traditional forest inventory, especially in the case of the remote, mountainous areas (Ziemblicki, 2015). Several studies discussed a disagreement concerning forest cover in Poland between the forest on the ground and official land cadastre (EGiB) and reported by the Central Statistical Office (Jabłoński, 2015; Jabłoński i in., 2018; Kolecka i in., 2018).

Since 2005, Bureau for Forest Management and Geodesy (BULiGL) started the national forest inventory (NFI). The NFI is a sampling-based inventory of the forest condition under all forms of ownership. The main aim of the NFI is to assess the state of the forest and the trends for large scale changes that occur over time. The measurements are performed on the permanent sampling plots grouped in five in the L-shaped cluster of 4x4 km grid located all over the country. The first and second series of NFI measurements covered forest located only on forest land according to the cadastre, while the third cycle includes also areas occupied by the forest vegetation, but not included in the cadastre records. In total, the network of NFI contains 98.9 thousand sampling plots (BULiGL, 2018). The state of the forest is updated on a national scale based on analytical calculations, thus it may not reflect the real forest situation on the ground and prevents the generation of forest cover maps presenting the spatial distribution of forests.

Due to the lack of up-to-date data on the spatial distribution and dynamics of forest changes and reported discrepancies between official statistics and real state of forests, it was rational to focus the research on the assessment of the usability of the advance remote sensing techniques and data to develop forest mapping methods and to track forest change over larger areas, at for example regional or national scale. Forest management process differs in terms of the scale of management (tree, separation, precinct, landscape, region, and country), planning level (strategic, tactical or operational) and purpose (e.g. harvesting, conservation of nature, preservation of biodiversity) (Bergsang. i in., 2015).

At the European and national level, knowledge about the state of forests provides support for the authorities responsible for environmental and forestry policies of the country and the European Union. At the regional level, information on spatial distribution of forests is essential for the forest planning and forestry management for all forms of ownership, control of the implementation of the National Forestry Extension Program and provision of information required for sustainable forest management, landscape protection and biodiversity analysis.

The rapid development of methods of remote retrieval of information about objects and the Earth observation, called remote sensing methods, resulted in increase interest in remote sensing technologies. Remote sensing data can be obtained from the low altitude (e.g. drones, portable platforms), air or satellite. The type of techniques and remote sensing data that can be used depends on the level and purpose of management.

Aerial remote sensing (e.g. laser scanning, aerial orthophotomaps, hyperspectral data) provides high detailed and precision data for relatively small areas, hence it is more often used to identify individual objects on a local scale. Acquiring and processing such data over a large area for example on a regional or national scale is costly and difficult to perform with a short period of time.

In case of large-scale studies and covering hard-to-reach areas, the solution is the use of satellite remote sensing. In recent decades, the rapid development of satellite technologies in the field of

Earth Observation has been observed, both in terms of technological progress related to the construction of new sensors, as well as the development of advanced methods of satellite data processing and analysis based on artificial intelligence, machine learning approached and using the cloud computation. There are a new constellations of satellites with increased spatial resolution currently being placed on orbit (currently the minimum size of the pixel available from commercial satellites is 0.3 m), the increased frequency of data acquisition, the same fragment of the Earth can be observed even daily (the constellation of the Planet Labs).

The great advantage of using satellite data is the possibility of moving back in time to the 60s70s of the last century due to the military spy satellites of the Corona system (data released in the 90s) or a series of civilian satellites of the Landsat mission initiated in 1972. A long time series of satellite data, reaching almost fifty years, allow you monitor the changes taking place on the Earth's surface. There are many examples of the use of satellite data from the Landsat mission to determine the state of forest areas, mainly concerning the structure of forests, i.e. forest cover and type, phenology (Banskota i in., 2014; Ji i Wang, 2016; Liu i in., 2018) and detection and monitoring of forest change at global scale (Hansen i in., 2013). The launch of the European Sentinel-2 satellites opened a new era in the application of freely available remote sensed data in forestry. In June 2015, due to the European Copernicus program, the first of the two Sentinel-2 optical satellites was launched. Two years later, in April 2017, the Sentinel-2B satellite was launched. The advantage of the Sentinel-2 mission is a higher temporal resolution. The same fragment of the Earth's surface is recorded every 5 days (in the case of Landsat it is 16 days), which increases the probability of a cloudless image and allows to capture the dynamics of forest changes. Sentinel-2 also has three times higher spatial resolution compared to Landsat satellites.

The Sentinel-2 offers 13 spectral bands, including four visible and near infrared bands at a 10 m spatial resolution (blue B2: 490 nm, green B3: 560 nm, red B4: 665 nm, NIR B8: 842 nm), four bands in red-edge and two bands in the shortwave infrared spectrum available at a 20 m spatial resolution (red-edge: B5: 705 nm, B6: 740 nm, B7: 783 nm; narrow NIR B8a: 865 nm, SWIR: B11: 1610 nm and B12: 2190 nm) and three bands at 60 m spatial resolution (costal aerosol B1: 443 nm, water vapour B9: 945 nm and SWIR Cirrus B10:1375 nm).

One of the biggest advantages of the Sentinel-2 mission is a wide swath covering up to 290 km (100 km wider than Landsat), which makes it ideal for analyzing the state of forests over large areas. Recently, there has been an increase in research publications focused on the use of the Sentinel-2 data in forestry, i.e. mapping forest cover (Escobar-Flores i in., 2018), forest type (Liu i in., 2018), classification of tree species (Immitzer i in., 2016; Persson i in., 2018; Wessel i in., 2018; Wittke i in., 2019). Many of these studies are still carried out on a local scale, while the number of studies conducted on a larger scale, at the regional and larger levels, is limited (Fassnacht i in., 2016).

Main aim of the research

The main aim of the monothematic publication cycle is to assess the use of satellite remote sensing to determine the distribution and spatial diversity of forest and to detect changes. The term "distribution" of forest areas refers to the occurrence, forest cover, and the phrase "spatial diversity" to the possibility of distinguishing elements that differ from one another within forests. In the case of my research, "spatial diversity" of forest concerns the division of forest area into deciduous and coniferous forest and the classification of the main tree species. An important element of the research is also detection of changes in forests based on satellite data, development of an innovative concept of the model allowing the interpretation of the factor causing changes in vegetation, including forests and assessment of the usefulness of multi-temporal Sentinel-2 satellite data to determine the forest damage caused by wind storm. The term "forest area" refers to land covered with forest vegetation, which according to the national forest definition as written in the Forest Act of 28 September 1991 (Journal of Laws of 1991 No. 101, item 444, art.3) occupy a compact surface of at least 0.1 ha, and are recorded and not recorded in the land cadastre.

The first part of my scientific research is focused on the methodical solutions related to the analysis of changes of vegetation cover, including forest at sub-continental and national level (**P1: Hościło et al., 2015**) and determination of spatial distribution of forests and detection of changes at the national scale (**P2: Hościło and Tomaszewska, 2015; P3: Hościło et al., 2016**). The second part of my research includes the development of a method for classification of forest areas, the type of forest (deciduous and coniferous), and main tree species based on the latest trends in the analysis of satellite imagery, such as the use of artificial intelligence for the classification of multispectral satellite images registered by the latest European satellites of the Sentinel-2 mission (**P4: Mirończuk and Hościło, 2017, P5: Hościło and Lewandowska, 2019**) and the assessment of the usefulness of Sentinel-2 data to determine the extent of forest damage caused by wind storm (**P6: Hościło and Lewandowska, 2018**).

The presented scientific achievement is in line with the latest research trends in the field of satellite remote sensing. My research concerns the methodological and application aspects. The developed method for classification of forest areas and dominant forest types are included in the web-based SAT4EST application that provides a tool supporting the management of non-state forests based on remote sensing data, which will be discussed in the further part of the summary of the achievements.

Implementation of the research aims and achieved results along with a discussion of their possible use.

Bezpośrednim czynnikiem, który wpłyną na moje zainteresowania związane z wykorzystaniem teledetekcji satelitarnej do badania obszarów leśnych były badania dynamiki zmian tropikalnych lasów bagiennych (w płd. części Borneo) pod wpływem pożarów będących efektem niezrównoważonej gospodarki człowieka. Badania te prowadziłam w ramach studiów doktoranckich w latach 2005-2009 na Wydziale Geografii na Uniwersytecie w Leicester (Wielka Brytania). W trakcie półrocznej przerwy w studiach doktoranckich pracowałam jako konsultant naukowy w projekcie badawczo-naukowym „*Kampar Peninsula Science Based Management Support Project (SBMSP*)”, w którym byłam odpowiedzialna za opracowywanie mapy typów lasów, mapy przedstawiającej stopień zniszczenia lasów tropikalnych na skutek nielegalnego pozyskanie drewna na półwyspie Kampar (Sumatra) oraz za odtworzenie przebiegu kanałów odwadniających na podstawie archiwalnych i aktualnych obrazów satelitarnych.

My research interest related to the use of satellite remote sensing for forestry started with the analysis of the dynamics of tropical peat swamp forest (in the southern part of Borneo) under the influence of fires resulting from the unsustainable forest management. I conducted this research as part of my PhD study (2005-2009) in the Department of Geography at the University of Leicester (Great Britain). During a six-month break in doctoral studies I worked as a scientific consultant in the research project "Kampar Peninsula Science Based Management Support Project (SBMSP)". I was responsible for mapping forest type and forest degradation levels caused predominantly by illegal logging at the Kampar peninsula (Sumatra) and for mapping the drainage channels based on archival and current satellite images.

The starting point for the research presented as scientific achievement, was the **work on the concept of a model that allows assessing the dynamics of changes in vegetation, including forests and automatic identification of sensitive areas** that are subject to changes as a result of climate change and human activities. I carried out this research during my postdoctoral work in the Department of Geography at the University of Leicester, under the supervision of Prof. Heiko Balzter. This work was carried out as part of the European project FP7 Geoland2, WP: Natural Resource Monitoring in Africa (NARMA). My research touched on an important application issue, which is the development of environmental indicators based on satellite observations that could be used by decision-makers in the process of natural resources management at the level of the European Union.

A decade of annual rainfall and vegetation data over sub-Saharan Africa was analysed using satellite-based rainfall estimates FEWSNET RFE 2.0 from NOAA's Climate Prediction Centre and the Normalized Difference Vegetation Index (NDVI) obtained from SPOT-Vegetation sensor. Rainfall and vegetation greenness trends were analysed for 759 administrative regions of sub-Saharan Africa to identify those regions that have experienced a negative, positive or stable rainfall/vegetation trend over the period 2001–2010.

The model is based on the spatio-temporal relationship between trends in annual max NDVI i rainfall divided in four categories representing areas in which: 1) there was a positive trend in the amount of rainfall, which translated into an improved condition of vegetation - "*climatic greening*", 2) a negative trend in the amount of precipitation translated into a decline in the condition of vegetation - "*climatic degradation*", 3) a decline in the condition of vegetation was observed despite the increase in the amount of precipitation - "*non-climatic degradation*" and 4) there is an improvement in the vegetation condition despite the negative rainfall trend – *"non-climatic greening"*. I implemented the proposed model using the IDL (Interactive Data Language) programming language. The concept of the model and results of its application was published in **P1: Hoscilo et al., 2015**.

According to the developed model, the improvement of vegetation condition due to the increasing amount of rainfall ("*climatic greening*") was observed mainly in the regions of the western Sahel, where many authors pointed to the effect of the so-called "greening" after long-term droughts in the 1980s of the last century. The improvement of the vegetation condition was also visible in eastern Africa, the eastern part of the Sahel and the central part of southern Africa, mainly in the mosaics of agricultural areas, which could be related to increasing productivity due to the growing vegetation period. The improvement of the vegetation condition, which is not related to the amount of rainfall, was observed fragmentarily in the central part of the Sahel, which is probably related to the process of artificial irrigation (27% of areas in this category are located in agricultural areas). Of interest, the greening" not associated with rainfall is observed in the tropical forest zone, where a slight reduction in rainfall does not limit the development of vegetation due to the generally very humid conditions. However, in the long term, prolonged water stress conditions can lead to a reduction of primary net productivity and changes in biodiversity (Gritti i in., 2010).

Areas showing vegetation degradation without connection with rainfall often occupy small fragments, located mainly in the eastern part of Sub-Saharan Africa (Ethiopia, central Somalia), southern part of Mali, central Cameroon. It is probably caused by the unsustainable land use, related to the growing demand for agricultural areas, pastures, "growing" cities, increased intensity of pasture use, and change of fire regime or illegal logging. According to the analyzes, around 8% of all areas that the model indicated as degraded without relation to the rainfall is located in forests, which may indicate an intensive process of deforestation.

The proposed model can be successfully used for rapid assessment of vegetation dynamics and identification of sensitive areas from regional to continental scale. By relating the results from the conceptual model to previously published studies, this article has demonstrated its general applicability and validity in areas where rainfall is the primary factor constraining vegetation growth, The model is less reliable in the wet tropics, where radiation is usually the limiting factor to vegetation growth. In addition, the model is based on NDVI, which tends to saturate in dense forest. The proposed conceptual model and achieved results were interesting for other scientists, The article **Hościło et al., 2015 [P1**] was cited 14 times by other authors. The proposed model allows for quick identification of sensitive areas, however, the interpretation of the indicated areas requires additional, detailed analysis of at a higher level of details using high spatial resolution datasets.

Therefore, at a next stage of my research I focused on more detailed mapping of land cover changes at the national level using multispectral satellite data. I explored this topic as part of the two projects carried out within the European Copernicus Land Monitoring program. These projects are the continuation of the CORINE Land Cover program. Both projects were financed by the European Environment Agency (EEA) and were led be myself. The CORINE Land Cover (CLC) program was launched in 1985. The main purpose of the CLC program is to provide up-to-date information on land cover and land use in a regular 6-year cycle across Europe and to show changes between successive cycles. Both the details and nomenclature meet primarily the needs of the European Union, including the Common Agricultural Policy and environmental policy conducted by the Directorate General and the European Environment Agency (EEA).

As part of the CORINE program, the Institute of Geodesy and Cartography developed national land cover / land use databases Corine Land Cover (CLC) for 1990, 2000, 2006, 2012, 2018 and land cover changes between subsequent inventory periods. The last two editions of national CLC2012 and CLC2018 were developed under my leadership. The particular databases were derived based on data from Landsat TM (CLC1990, 2000), SPOT4 / 5 and IRS-P6 (CLC2006), IRS-P6 and Rapid Eye (CLC2012) as well as Sentinel-2, Landsat 8 (CLC2018) satellites. Of the 31 land cover classes found in Poland, the 4 classes relate directly to forested areas: deciduous, coniferous and mixed forests as well as the class of transitional woodland-shrub. Mapping of land cover changes is carried out using an expert visual interpretation of satellite images.

The aim of the land cover change mapping between 2006 and 2012 was to map all changes greater than 5 ha, which are visible on the satellite images, then to build the CLC-change database and to generate the CLC2012 database. The quantitative and qualitative analysis of the changes in the period 2006-2012, showed that over 75% of all land cover changes in Poland took place in forest areas and in semi-natural ecosystems, 19% in anthropogenic areas, 5 % in agricultural areas and the remaining 1% covered wetlands and water **(P2: Hoscilo i Tomaszewska, 2015)**. Of interest, the forest classes revealed the positive balance (+ 28,000 ha), however forest was subject to the largest area of changes in the analyzed period. Over 100,000 ha of forests has been transformed into other land cover classes, including 94% in the transitional woodland-shrub class, which includes both logging areas as well as plantings and land subject to natural succession. The decline of the forest area was also related to the construction sites (2.5%) and increased extraction of natural resources (1.3%). Forest area increased by 99.7 thousand ha, of which 99.6% was transformed from the transitional woodland-shrub into forest class.

In 2018, I managed the works related to the inventory of land cover changes between 2012 and 2018 based on data acquired by the Sentinel-2 and Landsat 8 satellites. These works were carried out as part of a framework project being part of the Copernicus Land Monitoring services, financed by the European Environment Agency. After the completion of the project, I performed a spatial analysis of land cover changes and showed that the total area of changes was about 30 thousand ha greater than in the period 2006-2012 and accounted to 335.7 thousand ha (Hościło, 2019). Again, over 75% of all changes that took place in the analyzed period concerned forest areas.

About 169.7 thousand ha of forests have been transformed into other forms of land cover, of which 96% (163 thousand ha) was transformed into transitional woodland-shrub class (77% of these changes concerned coniferous forests). These transformations mainly covered forest areas which were damage by wind storm in August 2017. Further decrease in forest area occurred as a result of transformation of forests into construction sites (1.3%), mineral extraction sites (0.8%) and transport and communication areas (0.4%). In the period 2012-2018, the forest area increased by 67.7 thousand ha, of which 98% was converted from the transitional woodland-shrub class into the forest class forest (deciduous, coniferous or mixed). About 1.5% of arable land and grassland was afforested. According to the CLC databases, in 2012, the forest occupied 31.1% of the country and 31% in 2018, of which deciduous forests covered 16%, coniferous 58% and mixed forests 26%.

Analyzing the spatial structure and dynamics of forest changes based on the national CLC databases, it should be remembered about a minimum mapping unit of 25 ha and width of at least 100 m, and that the CLC-change contains real changes of a minimum area of 5 ha and width of least 100 m visible on satellite images. As a consequence, objects, like for example forest, buildings covering an area of less than 25 ha or roads narrower than 100 m will not appear in the CLC database. They undergo a generalization process and are included in the dominant class of land cover constituting homogeneous polygons with an area of over 25 ha, or belong to the mosaic classes of different land cover classes. Detailed analysis of the direction of changes taking place in forest areas is additionally hindered due to the existence of classes with a high degree of generality, e.g.: class transitional woodland-shrub contains clear cuts, damaged forest as well as afforested areas, subject to natural succession or planting. The technical assumptions of CLC are tailored to the needs of users responsible for environmental policy at the national and European level.

Considering the limitations of CLC databases related to the methodological approach, preventing a detailed analysis of land cover, spatial resolution, a large degree of generalization and a 6-year production cycle (insufficient to capture dynamically changing objects), in my further research I focused on obtaining a detailed information on the spatial distribution of forests in Poland. An additional motivation was the discrepancies indicated by several authors between the real forests on the ground and official cadastral data reported by the Central Statistical Office (Jabłoński, 2015; Jabłoński i in., 2018; Kolecka i in., 2015).

Knowing the limitations of national CLC databases, and on the other hand the need to generate a detailed digital map showing the actual distribution of forests at country level, I developed methodological approach for generating a forest extent map following the national forest definition in the Forest Act (1991) and forest definition according to the Kyoto Protocol, based on available spatial data obtained from various sources. This work was carried out under my supervision during the project "Inventory of real forest cover of the country using existing photogrammetric data, remote sensing data and other available spatial data" financed by the Directorate General of State Forests (DGLP).

The actual forest extent map, which refers to the national definition of forest as defined in the Forest Act of 28 September 1991 (forest by definition is a homogeneous area of 0.1 hectares). This includes all forms of ownership forests and areas that are forested, but officially recorded as non−forest. Moreover, the map of the forest extent under the Kyoto Protocol, including areas that meet the criteria of actual forest extent map and additionally forest areas designed or used for housing, recreation, infrastructure, and other industrial and agricultural areas (e.g.: permanent crops – orchards) were determined.

The proposed method of actual forest cover mapping was based on a synergy of the available spatial data containing information on forest coverage such as: Digital Forest Map (LMN) (covering explicitly the State Forests), Topographic Database (BDOT10K), Database of Parcel Identification System (LPIS) - zoning areas (PZ-LPIS) and Rural Development Plans (PROW-LPIS), National Forest Data Bank (BDL) and High Resolution Layer - HRL (Copernicus Land Monitoring product based on classification of satellite data) (Hościło i Mirończuk, 2016b).

To ensure high accuracy and reliability of the final product, in the first stage, detailed analyzes of the timeliness, content, completeness and coherence of individual source spatial data were performed. For the accuracy analysis, we applied the "random sampling" method using randomly selected control polygons 10 × 10 m. The results of the data accuracy analysis showed that the high resolution Copernicus layer has the highest "commission" error (7.5%), and the BDL the highest error of "omission" (16.7%). The lowest error of "omission" revealed BDOT (2.4%), HRL (2.5%) and PZ-LPIS (4.0%) layers. The "commission error" for BDOT, BDL and PZ-LPIS layers reached comparable values, respectively: 5.0%, 4.6% and 4.4%. An important aspect of determining both the actual forest cover and forest cover according to the Kyoto Protocol was the development of a spatial data integration method. For this, I proposed the use of map algebras with weighted parameters, which are the result of the accuracy assessment of individual spatial datasets. The highest weight was assigned to pixels, from LMN and PROW or their combination with other datasets and pixels that come from three or four sources. A lower weight was assigned for pixels from two sources with the lowest error of omission: BDOT + LPIS. The lowest weight was given to the pixels from two and one source. Pixels explicitly from the HRL have been removed due to a relatively large commission error (P3: Hościło et al., 2016).

The proposed method allowed determining the forest area with an accuracy of 99%, the "commission" error of 0.42%, the "omission" error of 0.89%. Based on the results, the actual area of forests according to the national definition amounted to 9997.7 thousands ha, which is 32.0% of the country's area, and is almost 800 thousands ha bigger than the forest area officially provided by the Central Statistical Office. According to the statistics, the forests in Poland amounted to 919.9 thousand ha, which is 29.4% of the country's area. Following the forest definition in the Kyoto Protocol, the area of forests occupied 33.5% of the country territory. For comparison, according to the National Center for Balancing and Emission Management (KOBiZE) responsible for estimating and reporting greenhouse gas emissions to the climate convention, the area of forests in Poland was accounted for 30% of the country's area (as of January 1, 2014).

The results of our study confirmed the discrepancy between the actual forest cover and the cadastral records. The actual forest area according to our study is around 213 thousand ha lower than calculated on the basis of statistical analyzes derived from a national forest inventory (WISL) by Jabłoński et al. (2018). For comparison, according to Jabłoński et al. (2018) forest area following the Kyoto Protocol is about 178 thousand ha lower than our assessment.

The assessment of the forest status and calculation of the actual forest cover area at country level carried out on basis on analytical approach makes it impossible to generate spatial maps of forest distribution and change maps showing the location, direction and actual area of changes. In addition, it should be stressed that each forest definition contains a criteria of a minimum size of the forest patch, which can only be applied using a spatial data. WISL data, as noted by Jabłoński et al. (2018), do not allow verification of the surface criterion.

The biggest discrepancy between the assessed forest area and official statistics at the district level was in the Podkarpackie (3.8%), Świętokrzyskie (3.7%), West Pomeranian (3.6%), Lubuskie (3.3%) and Silesia (3.2%). The discrepancies are probably associated with privately owned land not recorded as forest in the cadastral database. This is due to: lack of current simplified forest management plans, conducting inventories only over the land included in official cadastre, problem with reclassification of land according to the real use (Jabłoński, 2015). An important factor is also the natural forest succession visible on abounded agricultural areas (Kolecka i in., 2018).

An advantage of the proposed method of determining the actual forest extent is the possibility of generating digital maps showing the spatial distribution of forests within the country according to a) national definition of forest and b) definition of forest at the Kyoto Protocol. These maps provide information about the spatial, detailed distribution of forests regardless of the forest ownership and showed the need for the land cadaster update. In has to be stressed that the proposed method of forest extent mapping depends on the quality, accurse, completeness and timeliness of the spatial datasets. Some of the national databases, such as BDOT10K, provided the land cover data over the whole country, but their disadvantage is an irregular way of updating, which results in not uniform timeline of the available data at the country level.

Uniform timing in the large-scale analysis is possible to capture using the latest European Sentinel-2 satellites. With the launch of the Sentinel-2 twin satellites, it became possible to record the Earth's surface with high spatial and temporal resolution, allowing for at least several cloudless images of the same area within a year. An important aspect in case of large-scale analyzes, enabling the capture of a unified time state is a wide swath of Sentnel-2 reaching up to 290 km.

Knowing the advantages of Sentinel-2, I focused the further part of my research on the aspect of automatic classification of forest areas based on the advanced classification algorithms. Due to the technological progress in the computing power of computers, cloud solutions, as well as the constantly increasing number of satellite data, advanced classification algorithms are being improved. In recent years, it has been proved that algorithms based on machine learning and artificial intelligence allow obtaining more accurate results of classification of large data sets compared to conventional parametric image classification methods (Mountrakis i in., 2011; Rodriguez-Galiano i in., 2012). Currently, the machine learning algorithms such as Random Forest - RF (Rodriguez-Galiano i in., 2012), Super Vector Machines – SVM (Mountrakis i in., 2011), and Convolution Neural Network – CNN (Ayrey i Hayes, 2018; Hafemann i in., 2014) are being commonly used.

I started to study this aspect by examining the efficacy of the Support Vector Machine (SVM) approach for tree cover mapping based on Sentinel-2 images and exploring the potential of the Sentinel-2 data for the assessment of tree cover. The study area is located in the Forest Promotion Complex, which is a part of the Knyszyn Forest Landscape Park (**P4: Mirończuk i Hościło, 2017).** The SVM is a supervised non-parametric statistical learning technique. The SVM is based on the main hypothesis that the training set is linearly separable. The SVM classification was performed on the single images (spring and summer season) and on multi-date Sentinel-2 images (images from two dates classified simultaneously). In addition, the use of high-resolution bands and a combination of the 10 m and 20 m spatial resolution data was examined.

The overall accuracy for all performed classification was very high and reached the level of 99.6% for multi-date approach and 99.2% for single summer image. In both cases, the classification was performed using spectral bands at a spatial resolution of 10 m. The use of a combination of 10 and 20 m bands slightly lowered the accuracy. The analysis showed that the S-2 images acquired in the middle of the vegetation season, when the leaves are fully developed are more suitable for tree cover mapping. The discrepancy in the accuracy of the classification results between the single image and the combination of two images may be influenced by the low accuracy of the spring image classification. The high “commission” error of 1.7% was archived for 10 m bands and 2.5% for combination of 10 and 20 m bands. The "commission" error was also higher for a single image (3.3 – 4.8%) compare to the multi-date approach (0.8 - 2.4%). Visual assessment of the obtained results confirmed numerous "omissions" and "commission" errors in case of classification on individual images and "commission" errors on the edges of forests in case of a multi-date approach.

The launch of the twin Sentinel-2 A and B satellites, which move on the same orbit, increased the revisit time to five days, which resulted in a higher probability of getting a cloud free image. Thus, i examined further the advanced forest classification techniques, not only in terms of mapping forest cover, but also studying their spatial diversity, separation of deciduous and coniferous forest type, and classifying the dominant tree species using the multi-temporal Senitinel-2 data. The detailed classification of forest areas was carried out using the non-parametric machine learning method - Random Forest (RF) (Breiman, 2001). The RF is an ensemble learning technique where many decision trees are constructed based on a random sub-sampling of the given data set. The advantage of RF is that it can run effectively on large and multi-source data sets and it is relatively robust to outliers, a reduction of training data and noise. The RF classifier is less sensitive than other streamline machine learning classifiers to the quality of training samples and to over fitting, due to the large number of decision trees produced by randomly selecting a subset of training samples and a subset of variables for splitting at each tree node (Pelletier i in., 2016, Isuhuaylas i in., 2018; Wessel i in., 2018).

The main objectives of my study was: i) To examine the potential of the multi-temporal Sentinel-2 data and its combination with topographic variables (DEM, slope, aspect) for mapping the forest/non-forest cover and forest type, ii) to identify eight tree species: beech, oak, alder, birch, spruce, pine, fir and larch over a large mountain area at the regional scale. We investigated the impact of the forest type stratification on the results of tree species classification following two approaches: i) All species were classified together within the forest mask, and ii) broadleaf and coniferous tree species were classified separately within the forest type masks. The study site conducted an area of about 380 thousand ha, located in the mountain terrain in southern Poland on the Slovak border. The south-west part of the area belongs to the Podhale region and is located in the foothills of the Tatra range of the Carpathian Mountains and the rest of the area belongs to the Beskids Mountains. A part of it is occupied by the Nowy Targ district, which is used as an example for the application of remote-sensed techniques in operational management processes **(P5: Hościło i Lewandowska, 2019**). Nowy Targ district is one of the districts with the largest area of non-state forests, which covers about 67% of the districts area (GUS, 2017).

We used four cloud-free Sentinel-2 scenes acquired in different phonological seasons: 20 April 2018 (spring), 8 August 2016 (summer), 2 October 2017 (early autumn) and 12 October 2018 (mid-autumn). The reference data for forest cover, type and tree species were obtained from the national forest inventory (NFI) and digital forest map (DFM). The NFI data used in the analysis were inventoried in 2015 and 2016. We analyzed the DFM and selected the homogenous tree species stands where one tree species occupied more than 90% of the stand. The reference samples, representing eight tree species, were randomly selected from the tree species homogenous stands.

The reference samples were randomly divided with 60% used for training and 40% for accuracy assessment purposes within the forest/non-forest, forest type and each tree species class.

The classification process was divided into three levels of forest detail: i) mapping forest / non – forest covers, ii) classification of forest type—delineation of coniferous and broadleaf forests and iii) tree species identification. We used the Random Forest classier for each of the three levels of analysis. The classification performed at different data sets: i) multi-temporal Sentinel-2 (10 and 20 m spatial resolution) data stack; 40 variables and ii) the combination of multi-temporal Sentinel-2 data with DEM and topographic features such as the Shuttle Radar Topography Mission Digital Elevation Model - SRTM DEM, slope and aspect calculated form SRTM DEM, added to the data stack (43 variables). Both datasets were classified using exactly the same training sample set.

The classification of the forest and non-forest cover provided a high overall accuracy of 98.2% for multi-temporal Sentinel-2 with and without the topographic information. The overall accuracy declined slightly to 94.8% for the delineation of coniferous and broadleaf forest types. Of interest, the use of three topographic variables did not increase the accuracy of the classification of the forest/non-forest cover and forest type (broadleaf and coniferous). Our results confirmed that spectral bands derived from the multi-temporal Sentinel-2 data are sufficient to accurately map forest cover and to separate the broadleaf forest from coniferous forest over a large area. This finding was also proven by the study of Zhu and Liu [20] conducted in the second-growth forest in Vinton County, Ohio, USA. The authors concluded that the multi-temporal Landsat images are enough to distinguish broad land cover classes (including the broadleaf and coniferous forest). This research outcome should be taken into account for operational forest and forest type mapping at the regional and national scales.

In contrast, the importance of the topographic variables increased significantly in the process of tree species delineation. In our study, by combining the DEM, slope and aspect with the multi-temporal Sentinel-2 data, the classification of eight tree species improved from 75.6% (multi-temporal Sentinel-2) to 81.7% (classification without stratification, where all tree species were classified together) and reached the highest accuracy of 89.5% for the stratified approach. The importance of the topographic variables in the process of tree species delineation was highlighted by other researchers (Dorren i in., 2003; Liu i in., 2018).

The stratified, hierarchical approach to tree species classification examined in this study provided more accurate results compared to the non-stratified method. Comparing the performance of the classification of individual tree species, we obtained following the stratified approach, the highest user's accuracy for oak (95.1%) and beech (92.3%) followed by birch (90.6%) and alder (83.1%). Our results were more accurate than those achieved without stratification by other researchers (Immitzer i in., 2016; Stoffels i in., 2015; Waser i in., 2014). Wessel et al. [30] applied the stratified approach to delineate the oak and beech species in the Bavarian forest (using Sentinel-2). They first mapped the broadleaf forest, then classified the tree species within the broadleaf forest and achieved a high user accuracy of 94% for beech and 100% for oak species., however this study was conducted at the local scale. Regarding the separation of coniferous tree species, the best user's accuracy was obtained following the stratified approach for spruce (85%) and pine (84.1%), followed by larch and fir, with the user's accuracy reaching almost 80%. The result for coniferous species were comparable with those achieved by (Stoffels i in., 2015; Waser i in., 2014) and higher than acheaved by Immitzer i in. (2016).

The Random Forest classification method allows determining the ranking of variables, thus determining which variables have better predictive properties. Analyzing the importance of variables used in the classification process, we observed a discrepancy between the coniferous and broadleaf tree species. The visual 10 m Sentinel-2 bands, in particularly red and green bands (B4 and B3) followed by two SWIR bands (B12 and B11), were the most important for the separation of four coniferous tree species. In contrast, the visible bands were less important in the classification of broadleaf tree species, except for the red band (B4) derived from images acquired in autumn and spring. The high relevance of the visible bands is related to the absorption of photosynthetic pigment chlorophyll a and b. The red-edge bands (B5, B6 and B7) and two SWIR bands (B12 and B11) contributed the most to the results of the broadleaf tree species classification. The importance of red-edge bands in the classification of vegetation and separation of broadleaf species was highlighted by other studies.

It has to be highlighted that the accuracy of the classification strongly depends on the quality of the reference samples. There are a few issues to point out. First, the stand-based forest inventories provide information aggregated to the forest stand level with no information about the spatial variability of dominant tree species within the stand. Second, due to the dynamic changes of the forest status, the inventory data is not always up-to-date. In the case of our study, due to an outbreak of bark beetles, the spruce forest became very fragmented, and some of the randomly selected reference samples had to be moved to the remaining patches of nearby spruce forest within the homogenous spruce stand. Third, the information assigned to the stands can be incorrect, we observed that sometimes, the small fragments of the coniferous forest were present inside the homogenous broadleaf stands.

In general, the Sentinel-2 mission is perfectly designed for large-scale analysis. Due to a wide swath and dense series of the Sentinel-2 data, it is feasible to derive up-to-date forest cover and forest type maps at a high spatial resolution on an annual basis. The developed method of classification of forest areas and deciduous and coniferous forest allows for the automatic generation of digital maps showing the distribution and spatial diversity of forest areas at a regional scale. These digital maps supply the SAT4EST web-based services dedicated to the management of non-state forests. These maps were indicated by SAT4EST service users as the most desirable and necessary in the process of managing non-state forests.

The current and accurate digital forest map is also essential to limit the area of the spatial analysis of the forest changes. In the final stage, I focused my research on the assessment of Sentinel-2 data for detection of the large-scale changes in forests. This is particularly important in the case of sudden, unpredictable changes such as, for example, damage caused by windthrow, which occurred in August 2017. The estimation of damages over large areas was difficult due to the spatial scale of damages and limited access to damaged areas.

Knowing, on the one hand, the difficulties associated with airborne large-scale analyzes and on the other hand the capabilities of advanced satellite remote sensing, I examined the potential of the multi-temporal Sentinel-2 images for assessing the forest damage caused by the windthrow in August 2017 (**P6: Hoscilo and Lewandowska, 2018**). The assessment was performed using a difference between a normalized difference moisture index (NDMI) calculated based on the pre− and post−damage Sentinel−2 images. NDMI was calculated based on NIR (824 nm) that is sensitive to changes inside the leaf structure and SWIR (1610 nm) – sensitive to the water content changes in leaves. Then, for each pair of images covering the same area recorded before and after the storm, the differences in the NDMI value (dNDMI) were calculated. We also attempted to separate different level of damage: a) the areas with the severe damage and b) partially damaged areas, characterised by a mosaic of damaged and undamaged forest structure. Two classes of damage were separated on the basis of a visual analysis of image texture and dominant spectral reflections.

The result of this study revealed that the total damage area in forest is equal to 35.8 thousand ha, of which 27.7 thousand ha was damaged within the State Forests and 8.1 thousand ha outside the State Forests areas. The damaged area derived from the Sentinel-2 data over the forest managed by the State Forests was around 11 thousands ha lower than the area of forests qualified for renewals according to the preliminary estimated damage report (DGLP, 2017).

Sentinel−2 data revealed to be perfect data for large scale damage assessment and post-damage forest monitoring mainly due to the wide swath up to 290 km. The limitation of the optical sensors is the cloudiness. Unfortunately, in the case of this analysis, the first cloud free image was acquired 6 weeks after the windthrow. It reduces the potential of the single−source data for rapid assessment of damages. However, when analyzing the possibilities of determining the extent of forest damage, it should be remembered that in the case of partially damaged trees, significant changes in the foliage structure and water content in the leaves compared to undamaged forest stands will be visible after a longer period. The spectral reflection recorded by satellite sensors comes both from damaged trees and from the exposed lower floor of the forest. Information on the proportion of spectral reflection from the soil surface and vegetation could be used to determine the areas on which it is necessary to carry out cleaning and restoration works and areas that have the potential for self-renewal (Thorn S. i in., 2016; Żmihorski, 2010).

Summary of the main research results

- A proposed conceptual model allows the interpretation of the factors driving a vegetation changes, including forest changes through the analysis of the relationship between the precipitation trends, and the vegetation condition (expressed as max NDV). It can be used to quickly assess the dynamics of vegetation and identify sensitive areas from regional to national continental scale [**P1**]. However, the interpretation of the indicated sensitive areas requires additional, detailed analysis of the situation at a higher level of detail using data at higher spatial resolution.
- Corine Land Cover (CLC) databases provide regularly updated information on basic land cover and land use classes as well as changes occurring between successive cycles within the country. In 2012, the forest according to CLC2012 occupied 31.1% of the country, of which the broadleaf, coniferous and mixed forests covered 16%, 58% and 26%, respectively. In the period 2006-2012, the area of forests in Poland increased by 99.7 thousand ha, of which 98% was transformed from the “transitional woodland-shrub” class into the "forest" class [**P2**].
- Limitations of CLC databases related to the methodological approach, tailored to the needs of users responsible for environmental policy at the national and European level, spatial resolution, a large degree of generalization preventing a detailed analysis of land cover, and the 6-year production cycle is insufficient to capture dynamically changing features.
- The proposed method of integration of available multi-source spatial data on a national scale, preceded by a detailed analysis of the timeliness, content, completeness and consistency of individual spatial data allowed to generate a digital map showing the spatial distribution of forests and determining the actual forest area and forest cover according to

the provisions of the Kyoto Protocol. The accuracy of the proposed method depends on accuracy, timeliness and complete spatial data [**P3**].

- The results of the actual forest cover area at the national level confirmed the discrepancy between the forest area on the ground and forest area officially reported by the Central Statistical Office. Based on the analysis of spatial data, the actual forest area reached 32.0% of Poland and is by almost 800,000 ha larger than the forest area officially reported by the Central Statistical Office. According to the definition of forest included in the Kyoto Protocol, the area of forest calculated based on our method is equal to 33.5% of the country. The proposed methodology of mapping actual forest cover determined the forest area with an accuracy of 99% (the "commission" error of 0.42%, and "omission" error of 0.89%) [**P3**].

- Applications of innovative methods for classification of satellite data based on artificial intelligence and machine learning approaches: Support Vector Machines and Random Forest allows mapping the forest / non-forest cover with a total accuracy of 99% over the flat landscape [**P4**] and 98% in the mountain areas [**P5**].

- In the case of mountain landscape, the additional variables characterizing the terrain features added to the spectral information from Sentinel-2 did not improved the results of classification of forest cover and delineation of deciduous and coniferous forest, but significantly improved the classification results of the main tree species. The total accuracy of the classification of eight tree species increases from 76% in the case of a scenario without a digital terrain model, up to 82% in the case of adding a digital terrain model [**P5**].

- An additional significant increase in accuracy up to 89.5% for classification of four broadleaf trees species and 82% for classification of four coniferous species was obtained following the stratification approach, where the broadleaf species: beech, birch, oak , alder were classified inside the broadleaf forest mask and the coniferous species: pine, spruce, larch, fir inside the coniferous mask.

- In the case of the classification of broadleaf species following the stratification approach, the highest accuracy was obtained for beech (92.3%), oak (95.1%) and birch (90.6%) and the lowest for alder (83.1%). The result of classification of coniferous species was lower compared to deciduous species. The highest accuracy was obtained for spruce and pine (85%), and the lowest for larch and fir (almost 80%);

- Sentinel−2 data revealed to be perfect data for large scale damage assessment and post-damage forest monitoring mainly due to the wide swath up to 290 km. The limitation of the optical sensors is the cloudiness. Unfortunately, in the case of this analysis, the first cloud free image was acquired 6 weeks after the windthrow. It reduces the potential of the single−source data for rapid assessment of damages.

- The total forest damage is equal to 35.8 thousand ha, of which 27.7 thousand ha was damaged within the State Forests and 8.1 thousand ha outside the State Forests areas. The damaged area derived from the Sentinel-2 data over the forest managed by the State Forests was around 11 thousands ha lower than the area of forests qualified for renewals according to the preliminary estimated damage report **[P6].**

Final conclusions and indication of the possibilities of using research results

The main scientific achievement is the development of innovative methodological solutions involving the integration of spatial data and advanced classification based on artificial intelligence as well as assessing their application towards the operational mapping of forest extent and spatial diversity within the forest – detection of broadleaf and coniferous forest and classification of the main tree species. In addition, in the aspect of detecting changes in forests, a significant achievement was to develop and test the concept of a model that allows rapid detection of changes and interpretation of the factor causing the changes, as well as assessing the use of satellite remote sensing to determine the extent of forest damage caused by windthrow. An important advantage of the developed methods is the large scale of analysis, which is the advantage for the sustainable management of natural resources, determining the actual forest cover at the country level, verification of accounting the carbon content, estimation of emissions and CO_2 sequestration capabilities.

The developed methods and obtained results are of application nature and can be used for the following applications:

- The results of the proposed conceptual model enabling the interpretation of the factor causing the vegetation change as well as the results of the analysis of trends and anomalies in the amount of precipitation and vegetation condition were used for designing the concept of the information bulletin, so-called Country Environmental Profile. Bulletins were prepared for selected African countries. They contain concise information in the form of maps and statistics on the state of the vegetation, divided into second level of administrative units. The concept of the bulletin was presented to the European Commission (DG REGIO, DG GROW).
- The Corine Land Cover databases are used by public authorities, scientific institutions as well as private companies for environmental analysis, environmental impact assessment, spatial planning, monitoring of land cover changes in the long-term perspective, statistical analyzes on a regional and national scale.
- Determined actual forest cover based on the integration of available spatial data was used to identify the National Forest Inventory (WISL) sampling plots that are located in forest areas not included in cadastral records.
- A digital map showing the actual forest extent at the country scale could provide information on the area and places where there are discrepancies between the situation on the ground and the cadastral records.
- Determination of forest coverage according to the Kyoto Protocol (in statistical and spatial terms) could support the process of reporting of carbon content, CO_2 emissions for the international commitments under the Climate Convention and the Kyoto Protocol.
- The developed method for the classification of forest areas, broadleaf and coniferous forest and tree species based on the multi-temporal Sentinel-2 satellite imagery could be used to produce detailed maps of forest cover and forest type at the regional and national scale. This would enable detailed monitoring of forest resources regardless of the forest ownership over the large-scales, especially in forest areas that are not managed by the State Forests.

- The results of the classification of forest areas and deciduous and coniferous stands are incorporated into the SAT4EST web-based application dedicated to the management of non-state forests. The SAT4EST application is being developed as part of the "SAT4EST - Earth observation based service providing local administration in non-state forest management" funded by the European Space Agency, of which I am the main author and manager on behalf of the Institute of Geodesy and Cartography. More about the SAT4EST project at www.sat4est.pl. This is an example of a project implemented in cooperation with a private company; its objective is the commercialization of scientific solutions.
- The results of the analysis of the possibility of using images from Sentinel-2 satellites to estimate the forest damage caused in the windstorm in August 2017 may be used in crisis management, for quick estimation of forest losses and level of damages over a large area.

4.3. Description of other scientific and research achievements

The course of my research work before obtaining a doctoral degree

My interests in satellite remote sensing began at the master's studies at the University of Warsaw in the Department of Geography and Regional Studies. I learned there for the first time about remote sensing and I was eager to explore this subject. During my studies, I decided to choose a specialization dedicated to environmental remote sensing: Geoecology and Remote Sensing, in which in January 1999 I defended my Master's thesis entitled: "*Land use changes in the Narew River National Park between 1956 and 1997"*. The master's thesis was supervised by prof. Jan Olędzki. During my master study, I started engineering study at the Warsaw University of Technology, Department of Geodesy and Cartography with specialization in the Cadaster and Geographic Spatial Information Systems. In 2001, I defended my engineering thesis entitled "*Management of road networks in Geographic Information System*". I wrote the engineering thesis under the supervision of dr inż. Krzysztof Buczkowski.

In November 1999, I was employed part-time in the Institute of Geodesy and Cartography (IGiK) at the Department of Remote Sensing, as a geographer. Part-time work allowed me to continue in parallel my engineering studies, which I graduated from in 2001. In 2001, I obtained my first small grant from the Scientific Research Committee for research project "*Application of the satellite image as the basis for the tourist map of the Biebrza National Park*", I took the role of the project manager and investigator. During 2002-2005, I was employed as an assistant at the Remote Sensing Department of IGiK, where I was involved in the implementation of tasks related mainly to the processing of satellite imagery and spatial analysis. In 2003, I obtained another grant from the Scientific Research Committee for research entitled: "*The method for Investigating of bog systems degradation related to peatland fires based on information obtained by satellite remote sensing*". My scientific interests began to focus on the use of satellite imagery in various spectral ranges to study changes in wetland ecosystems. Initially, I studied the process of succession of woody-shrub vegetation in the bogs of the Biebrza National Park, which is the result of the progressing process of peatland's drainage. With the obtained scientific grant for the study of degradation of wetlands due fires, I began to examine the use of satellite imagery to study fire phenomena, including detection of burn areas, burn area mapping, monitoring the direction of fire spread. I also made a classification of plant communities before and after the fire based on satellite data. As part of the project, I attempted to measure the surface subsidence caused by fires using the GPS RTK (Real Time Kinematyc) method. The research was carried out over the Biele Suchowolskie in the northern part of the middle basin of the Biebrza National Park, where in September 2002 an intensive peat fire occurred.

In April 2005, I began a PhD study at the University of Leicester, in the Department of Geography (United Kingdom), where I received a doctoral scholarship. In my doctoral thesis I used the opportunity to further develop my research interests and knowledge gained during the work at IGiK in the use of satellite remote sensing for peatlands research and investigation of the fire phenomenon. The main goal of my doctoral thesis was to study the dynamics of land cover changes and the condition of tropical swamp forests, which have been degraded as result of repeated intense fires. The area of my research was located in the southern part of the Central Kalimantan province - the southern part of the Indonesian island of Borneo. This area is located within the scope of the former so-called "Mega Rice Project", which is considered one of the largest ecological disasters. The "Mega Rice Project" began in 1996; its main goal was to transform tropical forests growing mainly on peat soils into rice fields. The construction of wide and deep irrigation channels caused rapid draining of peat bogs and increased frequency of fires, which in turn led to irreversible degradation of the entire ecosystem and a sharp increase in greenhouse gas emissions released both during ground and underground (peat deposits) fires of biomass, as well as removed from over-dried peats. Using historical satellite data, I managed to recreate the history of fires in the studied area, which was necessary for understanding of the phenomenon of returning fires and the process of vegetation rebirth after a fire. I also dealt with modeling of carbon losses due to the burning the above- and belowground (peat) biomass. On December 18, 2009, I received a doctoral degree from the Senate of the University of Leicester. The title of my doctoral thesis was: "*Fire regime, vegetation dynamics and land cover changes in tropical peatland, Indonesia*". My doctoral thesis was supervised by Prof. Susan E. Page and Prof. Kevin Tansey from the Department of Geography at the University of Leicester.

During my PhD study (2005-2009) I had a short break, during which I worked as a scientific consultant in the research project "*Kampar Peninsula Science Based Management Support Project (SBMSP)*", financed by Asia Pacific Resources International Holdings Limited (APRIL), in cooperation with WL Delft Hydraulics from the Netherlands. My task was to develop a map of forest types, a forest degradation map showing the degree of tropical forest damage on the Kampar peninsula (Sumatra) and the reconstruction of the drainage channels based on archival satellite images.

In the period before obtaining the doctoral degree, I was a co-author of 3 scientific articles in journals from the Journal Citation Reports database (journals from the A list of the Minister of Science and Higher Education), 5 scientific articles in non-JRC journals (including one article in the journal from the list B MNiSW, in 2 articles I was the first author), 1 chapter in the monograph, 13 scientific publications in reviewed conference materials (including 6 as the first author), non popular science articles and 10 summaries in conference materials (including 3 as the first author). I prepared two reports on the results of the research grants. I presented the result of my studied as 7 oral presentation and presented 5 posters at 9 international and 3 national conferences. I also participated in 8 research projects, of which I led 2 national projects as project manager, and in the remaining 6 projects I was the investigator.

I also received the British Council award for Young Scientists in the form of a free participation in the "*International Networking of Young Scientists Event*" workshop in Malaysia. I have completed a number of scientific trainings organized by the University of Leicester.

The course of my scientific and research work after obtaining the doctoral degree

After obtaining the doctoral degree, I continued research related to issues of assessing the condition of vegetation and the dynamics of vegetation changes. In 2009-2011, I carried out a postdoctoral research at the University of Leicester, in the Department of Geography, where I was employed as Post-Doctoral Research Associate. My postdoctoral research was supervised by Prof. Heiko Balzter. During this time, I conducted research, as part of the European project FP7 Geoland2, WP Natural Resources Monitoring for Africa (NARMA), on indicators characterizing the condition of the natural environment in Africa. I carried out the analysis of dynamics of changes in vegetation at continental scale based on data from low-resolution satellites (SPOT Vegetation) and using the IDL programming language. The result of my research is a conceptual model of interpretation of changes in the vegetation condition, resulting from climatic changes or unsustainable human activity, which was indicated as part of the scientific achievement (**P1**).

In October 2011, I joined to the Remote Sensing Center team at the Institute of Geodesy and Cartography (IGiK) and was employed at the position of an assistant professor. From April to October 2012, I was on maternity leave. I was motivated to quick return to academic work by a grant received from the Foundation for Polish Science as part of the "POMOST" program, dedicated to parents-scientists who bring up small children and would like to return to academic work.

After returning to work at the Institute of Geodesy and Cartography my work focused on research in the field of:

1) Analysis of the possibility of using satellite remote sensing in the process of obtaining information on vegetation fires at a local and national scale;
2) Analysis of basic forms of land cover and detection of land cover changes using satellite remote sensing;
3) Analysis of the possibility of using satellite remote sensing in determining selected forest features, other than those described for scientific achievement, i.e. density of canopy closure, assessment of forest condition and, modeling the aboveground wood biomass.

Issues related to the analysis of the possibility of using satellite remote sensing in the process of obtaining information about vegetation fires at a local and national scale were mainly carried out in the framework of two research projects, in which I was the project manager. In the project: "*Application of remotely sensed data to the management of fire events in Poland*" funded by the European Space Agency (ESA) I dealt with the following issues: a) selection of "fire" pixels based on archived data from the NOAA AVHRR low-resolution satellites (data available in the IGiK archive); b) time-space analysis of fires registered by satellites based on available fire products, so-called "hotspots" generated on the basis of data from MODIS Aqua and Terra sensors, ATSR WFA and NOAA AVHRR; c) verification of fires recorded by satellites with fires registered in the National Forest Fire Information System (KSIPL), managed by the Forest Research Institute; d) analysis of the applicability of high resolution satellite images (visible and radar) to determine the burned areas; e) study the dynamics of vegetation regrowth, based on historical fires that took place in Poland in the 90s of the last century.

The results of comparison of "hotspots" recorded by satellites (SAT) with fires from KSIPL database showed a high error of "omission", on average 32.3% of SAT fires were registered in the

KSIPL in the period 2002-2014; only 20.2% of fires > 1 ha from KSIPL were registered by satellites. In total, around 45% of agreed fires are fires with an area of more than 5 ha, 42% are fires of less than 5 ha, but larger than 1 ha, and 13% are fires equal to 1 ha. Low agreement between fires registered by satellites and reported in the KSIPL results from both i) the limitations of satellite data (cloudiness, frequency of imaging), ii) size of fires (small fires of low intensity dominating in Poland are omitted), and iii) the nature of data contained in KSIPL. Due to the lack of accurate information on the location of the fire in the KSIPL database, the spatial comparison was carried out in the NUTS3 administrative divisions, including information about fire alarm, intervention time and fire duration (Hoscilo and Lewandowska, 2015; Hoscilo and Turlej, 2014).

The analysis of the estimation of burned area were carried out using the Normalised Burn Ratio index (NBR) based on spectral reflection in the near and short infrared range. The fire detection algorithm was tested over the historical forest fire in Kuźnia Raciborska, Puszcza Notecka and in Kadzidłowo (May 2014). The obtained results confirmed the effectiveness of the NBR index for determining the extent of fires. Radar data can be used to map the range of large-scale fires (difficulties with small fires).

As part of the "*A novel approach to estimate fire intensity and carbon emissions over the decade of fires in Poland*" project funded by the Foundation for Polish Science, I investigated the issue related to the intensity of fires and estimation of the emissions of gases: CO2, CO, CH4, NO and N2O as the result of biomass combustion following the conventional method of "bottom-up" and innovative satellite-based "top-down" method. The conventional method is based on the following parameters: burnt area, amount of biomass, amount of biomass burned and emission factors for individual gases. The "top-down" innovative method is based on information on the amount of radiation emitted in a given time by fire, which depends on the amount and type of burned biomass (Wooster et al., 2005). To calculate the emissions using the "top-down" method, I used the parameter called Fire Radiative Power (FRP). FRP is a measure of the amount of radiant heat emitted in a given time by fire (Kaufman et al., 1998). The FRP data provides information necessary to quantify the intensity of fires on the entire globe. FRP is determined based on data recorded by the satellites in the mid-infrared range (about 3.9 µm). I have analyzed the FRP value calculated on the basis of data recorded by satellite sensors: MODIS FRP and SEVIRI FRP. The MODIS FRP data is made available with the product "Active Fire - hotspots" in a spatial resolution of 1 km^2. SEVIRI FRP data is made available at around 3 km spatial resolution and very high temporal resolution of 15 minutes. I analyzed the intensity of fires in the period 2001-2013 for the entire territory of Poland, as: a) individual fire, which took place in the grid of 1 km^2 and b) large-scale fires - a cluster of individual pixels in which the satellite observed a fire. The analysis of individual fires concerned the study of variability of fire intensity depending on the fire season (spring, summer, autumn), the spatial scale and land cover types. The most intense fires (≥300 MW) occurred in the agriculture areas in 2002, 2003 and 2008. The analysis of average FRP values shows that peat fires are characterized by the highest FRP values. Analysis of the average FRP values for individual fire seasons confirmed that summer and spring fires are more intense (35 MW) than autumn fires (27 MW). Extremely intense fires occur more often in autumn and summer (Hoscilo and Lewandowska, 2015).

Fire Radiative Power values have been converted into Fire Radiative Energy (FRE) values, which is the total amount of heat emitted during a fire per unit of time. The FRE values were then used to determine the amount of carbon losses and CO_2, CO and other greenhouse gas emissions released during biomass burning (Wooster et al., 2005). The emission analysis was carried out at country level in the period 2001-2013 and for the wetland fire of the Biele Suchowolskie. The results of estimation of CO_2 and CO emissions from wetland fires using the top-down satellite method were similar to the calculated volume of emissions from the above-ground biomass using the traditional method (about 80,000 tons of CO_2 and 4,000 CO). The obtained results showed that the amount of GHG emissions calculated using the FRP indicator is underestimated by the amount of emissions from the combustion of the belowground biomass (peat layer burnt away). The obtained results indicate far to low values of conversion factors currently used for converting FRE values into biomass, there are should be adjusted to wetland ecosystems (Hoscilo and Lewandowska, 2015). In addition to the work carried out under the above mentioned projects, I also continued work related to mapping and monitoring fires using satellite data in Central Kalimantan, Borneo.

Issues related to the **analysis of basic land cover forms and detection of terrain coverage changes using satellite remote sensing** were carried out mainly within two projects, which I was a project manager, financed by the European Environment Agency (EEA), as part of the European Copernicus program. One of the tasks was to carry out the inventory of land cover and land use changes in Poland in the period 2006-2012 and 2012-2018 based on satellite imagery and to generate Corine Land Cover databases - CLC2012 and CLC2018 (described in the part of scientific achievement). In addition to the production of CLC databases, I also managed the work related to the verification of High Resolution Layers (HRL), containing detailed information on the characteristic forms of land cover. These layers are complementary to Corine Land Cover databases and illustrate the degree of soil imperviousness, forest areas, permanent grasslands, wetlands and water reservoirs. Spatial resolution of all layers is 20 x 20 m. HRL are created in the process of automatic classification of multitemporal high resolution satellite images. They are prepared for 39 European countries by consortia of private companies selected through a tender by the EEA. High resolution layers can be used to specify information about land cover, e.g. in the process of environmental impact assessment (Hościło and Mirończuk, 2016a), obtaining information on the spatial distribution of forests (Hoscilo et al., 2014). However, the 3-year cycle of production of HRL, time lag in data provision and accuracy of HRL products, not always meets the expectations of end users. For example the omission error of the imperviousness layer was equal to 6% and the commission error - 26%. The dominant leaf type, divided into broadleaf and coniferous trees, is characterized by lower accuracy of broadleaf forests compared to coniferous forests. The omission error in the case of broadleaf forests was over 15% and the commotion error was almost 9%. The extent of broadleaf forests is overestimated at the expense of coniferous forests (Mirończuk et al., 2019a).

We have also verified the products of the local component of the Copernicus Land Monitoring service, which provide detailed information on land cover and land use in the functional zone of urban areas (Urban Atlas), along rivers (Riparian Zones) and in selected Natura 2000 (meadow areas). The minimum mapping unit for Riparian Zones and Natura 2000 products is equal to 0.5 ha, while in Urban Atlas - 0.25 ha. In order to increase the thematic detail of the Urban Atlas product, we enhanced the product by adding information about the main and secondary land use type to the existing Urban Atlas polygons. In this way, it was possible to make analyzes of the spatial diversity of information on land use. In addition, an analysis of the accuracy of the additional information layer of the Urban Atlas product, showing the height of buildings (Copernicus Buildings Heights 2012) for Warsaw was examined (Kałuski et al., 2018).

Another area of my research is the **analysis of the possibility of using satellite remote sensing in determining selected forest features, other than those described for scientific achievement, i.e. forest canopy density, forest condition, modeling aboveground wood biomass.** Two projects funded by the European Space Agency (ESA) deserve special attention:

Project: ***„SAT4EST*** *- Earth observation-based service supporting local administration in non-state forest management",* is funded by ESA as part of the Polish Incentive Scheme (2017-2019). The main purpose of the SAT4EST project is to design the system and build an web-based service supporting the management of non-state forests based on satellite Earth observation techniques. This is an example of a project implemented in cooperation with a private company, whose objective is the commercialization of scientific solutions. I am the main author and coordinator of the project on the IGIK side.

The SAT4EST system and service is dedicated primarily to local administration and companies taking part in the process of preparing documents necessary to manage non-state forests. According to law (act. 5 of the Forest Act of 1991), the local governor is responsible for managing th non-state forests. The main problem in supervising is i) the lack or not up-to-date simplified forest management plans (UPUL) for non-state forests, ii) discrepancy between the official cadastre records and the state on the ground, iii) the large fragmentation of forest patches (Ziemblicki, 2015). Therefore, i focused my research on developing the operational methods for generation of forest related products based on satellite remote sensing that would meet the expectations and requirements of end users.

The SAT4EST system consists of a satellite component (data collection and processing), in situ component and a map server for visualization and data sharing. So far we have managed to develop highly automated procedures for processing and analysis of the Sentinel-2 data to perform:

• Classification of forest areas and division of forests into deciduous and coniferous stands - indicated as part of scientific achievement (**P5**);

• Detection of forests changes at spatial resolution of 10 x 10 m. According to the user requirements document, the map of forests changes is the second most awaited product. We conducted research on the automatic method of forest change detection in the annual cycle (required by users) and experimentally "image to image". Studies have shown that the most accurate results are obtained on the basis of the multi-temporal analysis of images obtained in a similar phenological phase of plants, preferably in the summer. We obtained the best results after using a combined method based on the difference of two spectral indices and selected spectral channels. The "image to image " method gave satisfactory results in flat landscape, but it did not work well in over the more complex terrain;

• The assessment of the condition and health condition of forests is performed on the basis of spectral indicators taking into account the content of chlorophyll, and other pigments and water contents in leaves calculated on the basis of selected spectral channels;

• Canopy closure, showing the proportion of the pixel covered by tree crown. It was developed based on Random Forest modeling. The reference data for the model were generated on the basis of a visual interpretation of available orthophotomap. Accuracy of canopy closure is calculated based on a 30% of the randomly selected reference samples. The correlation between the modelled and reference data was equal to R^2 = 0.899.

As part of the SAT4EST service, we also offer products on demand, for example: the extent of forest damaged by wind storms (Hoscilo and Lewandowska, 2018), fires (Hoscilo and Lewandowska, 2015), insect outbreak (Mirończuk et al., 2019b) and assessment of woody biomass (Hoscilo et al., 2018). The SAT4EST project is implemented in three pilot districts in Legionowo, Nowy Targ and Sieradz. The service is in the pre-operational phase, is currently being tested in pilot districts. More information about the project: www.sat4est.pl.

The ESA DUE GlobBiomass project (2017-2018) was carried out by an international consortium of the leading experts in the field of Earth Observation led by the Department of Earth Observation at the University of Friedrich-Schiller in Jena (Germany). The consortium was made by 14 institutions from eight European countries, including Poland: the Remote Sensing Center of IGIK and the Forest Research Institute. I was coordinating of the work carried out by the Polish institutions, I was the task leader, participated also in the conceptual work and modeling of wood biomass. The main goal of the GlobBiomass project was to develop a global product presenting the global distribution of biomass and estimation of forest biomass for five regions located in different climate zones: Sweden, Poland, Indonesia (southern Borneo), Mexico and South Africa.

I was responsible for the work related to the development and production of the first national maps of aboveground woody biomass. These maps were developed for 2005, 2010 and 2015 at a national scale. The maps of wood biomass were developed using archival and currently available remote sensing data recorded in the microwave and optical wavelength. Biomass maps for 2005 and 2010 were derived based on a mosaic of radar data (ALOS PALSAR - L-band) and optical data from the Landsat 5 mission. For the biomass map of 2015, we used the multi-temporal radar data recorded by the European satellite Sentinel-1 (C-band) and optical data from the Sentinel-2 satellite. As the reference data, we used the sampling plots from the National Forest inventory (WSL) for the years 2005/2006, 2009/2010 and 2015/2016. The Forestry Research Institute was responsible for the calculation of the aboveground biomass from the sapling plot data. The biomass calculated in this way was used as reference data for biomass modeling. The reference data was divided into a training set - 70% and verification - 30% of data.

We used the Random Forest regression method for biomass modeling. As explanatory variables in the case of the 2015 map, we used the multi-temporal data from Sentinel-1 (C-band). We calculated the multi-temporal sum and median of the radar backscatter coefficient, separately for of VV and VH polarization (data from the period 2015-2016) and separately for the summer and winter seasons. In addition, a mosaic of four spectral channels (optical and near infrared) generated from multi-temporal Sentinel-2 data were added to the set of explanatory variables. We modeled the biomass individually for each of the orbits of the Sentinel-1, then the results of individual models were combined into one map (Hoscilo et al., 2018). Biomass modeling for 2005 and 2010 was based on ALOS PALSAR mosaics for 2005-2007 and 2009-2011. A mosaic of spectral (optical and near infrared) bands generated from multi-temporal Landsat-5 data (Hoscilo et al., 2016; Rodríguez-Veiga et al., 2019) was added to the set of the explanatory variables.

The assessment of the accuracy of the biomass modeling result was carried out using the 30% of the reference data and independently for selected forest districts, using the data from the Digital Forest Map (DFM). The accuracy analysis showed a general tendency to overestimate the value of low biomass <100 t / ha and underestimate the value of high biomass above 250 t / ha. The highest agreement was obtained in the range of 100-250 t / ha. Independent assessment of the results of biomass modeling made on the basis of data from the DFM for several forest districts confirmed relatively high agreement with biomass at the stand level (Hoscilo et al., 2018; Hoscilo et al., 2016; Rodríguez-Veiga et al., 2019). The national wood biomass maps are available on the project website: www.globbiomas.org.

In the post-doctoral period, I was involved in the implementation of **17 research projects** funded by the European Commission (5 projects), the European Environment Agency (2 projects), the European Space Agency (3 projects), the Japanese Space Agency (1 project), and the General Directorate of State Forests (2 projects), Foundation for Polish Science (1 project), National Center for Research and Development (1 project), Ministry of Science and Higher Education (1 project), German Ministry of Education and Research (1 project). **I am the author of 8 projects in which I have been the project manager**. These are projects funded by: the European Environment Agency, European Space Agency, Japanese Space Agency, General Directorate of State Forests, Foundation for Polish Science and the Ministry of Science and Higher Education. In other projects, I was the coordinator of tasks on the IGiK's side or the investigator. In the case of projects founded by the European Environment Agency, I coordinated the work of a large project teams. In addition, one of the projects (SAT4EST) founded by the European Space Agency, of which I am the main author and coordinator of the IGiK, is an example of a project implemented in cooperation with a private company. The assumption of the SAT4EST project is the commercialization of scientific solutions. In 2014, I completed the training in the field of commercialization of science and entrepreneurship developed by the Kauffman Foundation, organized by the Foundation for Polish Science.

I participated in numerous working meetings related to international and national projects. I actively participated in 9 meetings of the National Reference Center (NRC) of the European Environment Information and Observation Network (EIONET) for land cover organized by the European Environment Agency. As a representative one of the NRC for land cover, at the request of the EONET National Contact Point (NFP), I commented on 10 initial reports on the state of the European environment prepared by the European Environment Agency.

I was a reviewer of 13 publications (including 1 before the PhD) submitted for publication in the international journals from the A list of the Ministry of Science and Higher Education (7 journals: International Journal of Wildland Fires, International Journal of Applied Earth Observation and Geoinformation, International Journal of Digital Earth, European Journal of Remote Sensing, Journal of Tropical Forest Science, Ecohydrology, Polish Journal of Environmental Studies) and from the list of B of the Ministry of Science and Higher Education (2 journals: Papers on Global Change PAS, Miscellanea Geographica).

In the period after obtaining the doctoral degree I was the author / co-author of:

- 9 scientific publications (including 6 as leading author) in journals included in the Journal Citation Reports database, with a total IF = 27.825 and 310 points (before the PhD IF = 9.796 and 110 points);
- 4 scientific publications in journals from the B list of the Ministry of Science and Higher Education with a total of 15 points according to the MNiSW (before the PhD 1 article from the list of B list of MNiSW and 4 other publications);
- 7 chapters in monographs (before doctorate 1 chapter);
- 11 scientific articles in reviewed conference materials, including 7 as the leading author (before doctorate 14, including 6 as the leading author);
- 4 popular science articles (1 before doctorate);
- 36 abstract in conference materials, including 21 as the leading author (before doctorate 10, and 3 as the leading author);
- 38 oral presentations and 11 posters presented at 20 international and 19 national conferences (before the doctorate, 7 oral presentations, 5 posters at 9 international and 3 national conferences);
- 8 final reports summarizing the projects (3 reports before doctorate);
- participation in 17 research projects, of which 8 as a project manager (before doctorate, participation in 8 projects, including 2 as a project manager).

The total IF according to the Journal Citation Reports (JCR), (according to the year of publication) is IF = 37.621, for the post-doctoral period IF = 27.825. The total number of points according to the list of scientific journals of the Ministry of Science and Higher Education (according to the year of publication) is 445 (list A: 420, list B: 25), for the post-doctoral period is 325 (list A: 310, list B: 15) . My scientific papers were quoted 257 times (including 253 times without self citation) according to the Web of Science Core Collection database (accessed on 24/04/2019). Hirsch index according to the Web of Science database (WoS): H = 8 (accessed on 24/04/2019).

For my scientific achievements I was twice (in 2014 and 2017) awarded the prize of the Director of the Institute of Geodesy and Cartography. In 2013, I received the award of the Director of the Institute of Geodesy and Cartography for activity in obtaining research projects. In 2012, I became a laureate of the Foundation for Polish Science, POMOST program - for parents-scientists to facilitate the return to research work after a break related to children.

I participated in the short-term trainings in the field of advanced technological solutions of satellite remote sensing, programming and building databases. At the University of Jena, I completed training dedicated the use of radar data and object classification, at the University of Leicester - training of Python programming. I also participated in the training organized by the ESRI in the field of building databases.

4.4 Academic and popularizing achievements and information about the international cooperation

Academic and popularizing achievements

From the beginning of my academic career I have been associated with my first Alma Mater - the Department of Geography and Regional Studies at the University of Warsaw (WGiSR UW). Already as a freshly graduated MSc I conducted field work for students specializing in remote sensing in Szymbark. As a PhD student at the University of Leicester, I taught courses of "*Geographical Information System*" for the BSc students and "*Digital Remote Sensing*" for MSc students. I also prepared the training material entitle: "*Extracting statistics from the MODIS burned area product*", which was used during the workshops: "*CarboAfrica: Remote Sensing of Fire for National Greenhouse Gas Accounting*".

After obtaining the PhD degree and returning to Poland, since 2013 I regularly give lecture entitled: "*The use of satellite data and products for fire analysis*" for MSc students at WGiSR UW. I have prepared the training materials "*Spatial Analysis of the Product" Active Fire - hotspot "for Poland*", which are given by myself, but also by other academic teachers for students of WGiSR UW. In 2013-2014, I developed and conducted in English language the lecture for students of the Erasmus program: "*Fires from space", "Controlling the remote senses to the management of the peatland vegetation" carbon dynamics"*, conducted at Inter-faculty Studies in Environmental Protection. In 2016, I conducted the practical exercise on "*Spatial Decision Support in ArcGIS*" for the international Erasmus Mundus students - "*Geo-information Science and Earth Observation for Environmental Modeling and Management (GEM*)". In 2017, I gave a lecture on "*Satellite technologies as a tool supporting the assessment of the condition of tropical peat forests on the example of Indonesia*", at the faculty seminar at the Department of Biology of the University of Warsaw.

In addition, I prepared training materials and conducted two trainings on the technical assumptions of the Corine Land Cover databases, interpretation of land cover and land use changes on the satellite images and the use of the InterChange program dedicated to mapping land cover changes under the Corine Land Cover program. The training was dedicated to the project team involved in the production of CLC2012 and CLC2018. In 2013, during the summer school organized by in the framework of the international GIONET project - GMES Initial Operations - Network for Earth Observation Research Training, I gave a lecture and practical training on the Corine Land Cover program in for national and international workshop participants.

In the period 2009-2010, I was supporting the supervision of two Master's theses and the one internship at the Department of Geography, University of Leicester. After obtaining the doctoral degree, in the period 2013-2018, I was a supervisor of two MSc theses and two BSc theses at the Department of Geography and Regional Studies of the University of Warsaw. I supported the supervisor of two PhD theses: M. Offowno and S. Shrestha, conducted under the supervision of Prof. dr hab. Katarzyna Dąbrowska-Zielińska and dr inż. Zbigniew Bochenek from IGiK. I was supervising the MSC student who received the scholarship of the Foundation for Polish Science (2013-2015) as part of the project: *"A novel approach to estimate fire intensity and decent of the decade of Poland" and* the internship *carried out the research as part of the project:* "*TURBATS: Spatial statistical modeling to assess the wind energy allocation and improve bat*", at the Helmholtz Center for Environmental Research in Leipzig (UFZ), Germany, 2016. In addition, I was the scientific supervisor of two interns from the University of Warsaw and the Military University of Technology.

I shared also my knowledge and many years of experience with participants of two start-up acceleration programs: Space3AC and BalticSatApp, during which I served as a mentor.

I am happy to participate actively in science-popularizing activities: the Science Picnic of the Polish Radio and the Copernicus Science Center (18 and 20 Science Picnic), Science Days on Foksal, "Why do we need space?", GIS Day. In 2018, I gave a lecture entitled "*Earth seeing by satellites - to whom and what satellite images are used for?*" addressed to high school youth during the European Night of Researchers organized by the Department of Geography and Regional Studies, University of Warsaw. I was also invited to the GIS Day 2018 organized by the Department of Geography, Nicolaus Copernicus University in Toruń, where I delivered a speech on "*SAT4EST-a satellite platform supporting the management of non-state forests*". In addition I conducted classes promoting satellite technologies for pre-school children ("Żyrafa" kindergarten).

I have also published results of my research projects (three short articles) in popular science magazines: Las Polski and Głos Lasu.

Organization of conferences and scientific meetings

I participated in the organization of 3 scientific conferences. I was the main organizer of the international workshop for young scientists organized as part of the "*3rd GIONET Summer School of Remote Sensing Applications for environmental modeling and classification*" (19-27.09.2013, Warsaw). I organized a one-day conference "*Fire monitoring - terrestrial and satellite methods*", in which representatives of 8 national institutions participated and co-organized the workshop "*New technologies for forestry*", under bilateral cooperation with Germany - BIOFOR project (7-8.06.2018, Warsaw), in which representatives of 11 national and 1 foreign institutions took part. I was the main organizer of the seminar finalizing the Copernicus projects: "*Copernicus services coordinated by the European Environment Agency with a source of information on land cover*" organized on 27 February 2019 in the Ministry of the Environment. The seminar was attended by 66 people representing various public administration institutions, government agencies, scientific institutions, the Central Statistical Office and the Polish Space Agency. In addition, I chaired five scientific sessions at four international and one national conference, and co-organized one plenary session at the 34th International Conference EARSeL (16-26.06.2014, Warsaw). In 2018, I took part in an expert panel discussion organized by the Forest Research Institute: "*Modern methods of remote sensing in environmental monitoring*" at the POLOCO Environmental Fair in Poznan.

Information about the international cooperation

I actively participate in bilateral international programs for scientific and scientific-technical cooperation with Germany and the Republic of Belarus. I am the manager on the Polish side of the "*Remote Sensing as a tool for the monitoring of wetlands under Ramsar convention*" funded by the Ministry of Science and Higher Education and the Ministry of Science of the Republic of Belarus. As part of this project, we cooperate with scientists from the Belarusian Academy of Sciences, from the Scientific-Implementation Center for Natural Resources. Cooperation with scientists from the University of Jena (Germany) takes place within the framework of the program "*Creation and extension of joint scientific structures in Europe*", founded by the German Ministry of Education and Research, BIOFOR: Biomasse-Forschungsstruktur (Biomass Estimation Knowledge Structure). In 2015, I participated in the program of creating institutional networks, the so-called "*IncoNet Central Asia Twinning Grant: Adapting to climate change: food security in Central Asia*", where as part of establishing cooperation with the countries of Central Asia (Uzbekistan and Kazakhstan) I took part in two scientific workshops on which I gave a lecture on "*Remote tools for assessing and fighting soil salinity in the Aral Sea Basin"*. I am a member of the expert team (scope of remote sensing and geoinformation) of the Erasmus + program within the EO4GEO project - "*Copernicus user uptake" geo-information sector supporting skills and capabilities”*.

I participated in the following international programs:

- Copernicus Land Monitoring program,
- GIO Land Monitoring program,
- Programs of the European Space Agency (ESA Polish Incentive Scheme Program, DUE, ESA PECS),
- European Maria Curie Action Program,
- European framework programs (Twinning Grants IncoNet, FP7, FP6, FP5),
- European Erasmus +, Erasmus and Erasmus Mundus programs.

I am active on forums of international and national scientific organizations. I actively participate in international conferences organized by IEEE International Geoscience and Remote Sensing Symposium (IGARSS), the European Association of Remote Sensing Laboratories (EARSeL) and ESA Living Planet, as well as national conferences. National Conference of Photointerpretation and Remote Sensing and seminars organized by the Remote Sensing Section of the Space and Satellite Research Committee at the Presidium of the Polish Academy of Sciences.

I am a member of the Remote Sensing Section of the Space and Satellite Research Committee at the Presidium of the Polish Academy of Sciences, the Space and Satellite Research Committee for the COPERNICUS Earth Observation Program and IEEE - the Institute of Electrical and Electronics Ang.ineers, GeoScience and Remote Sensing Society. During the post-doctoral internship I was a member of the Remote Sensing and Photogrammetry Society (RSPSoc), the International Peat Society (IPS) and a member of the Scientific Council and Ethics Committee at the Department of Geography of the University of Leicester. Since 2013, I am represent one of the National Reference Center (NRC) for land cover (located at the Institute of Geodesy and Cartography). In 2015, I was appointed a deputy chairman of the COST Action Management Committee ES1104: Arid Lands Restoration and Combat of Desertification: Setting Up a Drylands and Desert Restoration Hub, institution appointing: Minister of Science and Higher Education.

I take active part in the work of the Institute of Geodesy and Cartography and activities promoting the Institute and the activity of the Remote Sensing Center. From June 1, 2014, I am the head of the Laboratory for Remote Sensing of Environmental Threats at the Remote Sensing Center, IGIK. Since 2013, I have been a member of the Scientific Council of the Institute of Geodesy and Cartography. I was also the chairman of the Election Commission to the IGIK Scientific Council.

A detailed list of published scientific papers, presentations, projects carried out together with information on other scientific, research, didactic-popularizing and organizational achievements is presented in Attachment 4.

References (positions in bold refer to the publications being a part of the scientific achievement)

Ayrey E., Hayes D.J. The Use of Three-Dimensional Convolutional Neural Networks to Interpret LiDAR for Forest Inventory. Remote Sensing (2018) 10:649.

Banskota A., Kayastha N., Falkowski M.J., Wulder M.A., Froese R.E., White J.C. Forest Monitoring Using Landsat Time Series Data: A Review. Canadian Journal of Remote Sensing (2014) 40:362-384.

Bergsang. E., Ørka H.O., Næsset E., Gobakken T. Assessing forest inventory information obtained from different inventory approaches and remote sensing data sources. Annals of Forest Science (2015) 75:33-45.

Breiman L. Random Forests. Machine Learning (2001) 45:5-32.

BULiGL. Wieloobszarowa Inwentaryzacja Stanu Lasu w Polsce wyniki za okres 2013-2017. (2018) Sękocin Stary: BULiGL.

CILP. Lasy w Polsce 2017. (2017) Warszawa.

DGLP. Stan siły wyższej o zasięgu ponadlokalnym w Państwowym Gospodarstwie Leśnym Lasy Państwowe zaistniały w dniach 11 i 12 sierpnia 2017 r. Biuletyn Informacyjny Lasów Państwowych. (2017).

Dorren L.K.A., Maier B., Seijmonsbergen A.C. Improved Landsat-based forest mapping in steep mountainous terrain using object-based classification. Forest Ecology and Management, (2003) 183:31-46.

Escobar-Flores J.G., Lopez-Sanchez C.A., Sandoval S., Marquez-Linares M.A., Wehenkel C. Predicting Pinus monophylla forest cover in the Baja California Desert by remote sensing. Peerj (2018) 6:1-17.

Fassnacht F.E., Latifi H., Stereńczak K., Modzelewska A., Lefsky M., Waser L.T., Straub C., i in. Review of studies on tree species classification from remotely sensed data. Remote Sensing of Environment (2016) 186:64-87.

Franklin S.E. (2001) Remote Sensing for Sustainable Forest Management USA: Lewis Publishers: Boca Raton, Taylor & Francis Group, LLC.

Gritti E.S., Cassignat C., Flores O., Bonnefille R., Chalie F., Guiot J., Jolly D. Simulated effects of a seasonal precipitation change on the vegetation in tropical Africa. Clim. Past 6: . Climate of the Past (2010) 6:169-178.

GUS. Bank Danych Lokalnych. https://bdl.stat.gov.pl/ (2017).

Hafemann L.G., Oliveira L.S., Cavalin P. (2014) Forest Species Recognition Using Deep Convolutional Neural Networks. 22nd International Conference on Pattern Recognition. 1103-1107.

Hansen M.C., Potapov P.V., Moore R., Hancher M., Turubanova S.A., Tyukavina A., Thau D., i in. High-Resolution Global Maps of 21st-Century Forest Cover Change. Science (2013) 342:850-853.

Hościło A. (2019) Sprawozdanie końcowe z projektu ramowego Copernicus Land Monitoring - Poland, Specific contract No 3436/R0-COPERNICUS/EEA.56948 Implementing Framework service contract, No EEA/IDM/R0/16/009/Poland--IGIK, ed. Warszawa.

Hoscilo A., Balzter H., Bartholomé E., Boschetti M., Brivio P.A., Brink A., Clerici M., i in. A conceptual model for assessing rainfall and vegetation trends in sub-Saharan Africa from satellite data. International Journal of Climatology (2015) 35:3582-3592.

Hosciło A., Dębowska A., Ziółkowski D. (2014) Numeryczna mapa terenów zadrzewionych. In: VII Conference "Geomatyka w Lasach Państwowych" 16-18.09.2014, Rogów.

Hoscilo A., Lewandowska A. Remotely detected fire events: potential and challang.es of validating against national ground dat. In: IEEE Geoscience and Remote Sensing (IGARSS2015) (2015) 26-31.07.2015, Milan, Italy:2159-2162.

Hoscilo A., Lewandowska A. Zastosowanie danych z satelity Sentinel−2 do szacowania rozmiaru szkód spowodowanych w lasach huraganowym wiatrem w sierpniu 2017 roku. Sylwan (2018) 162:619−627.

Hościło A., Lewandowska A. Mapping Forest Type and Tree Species on a Regional Scale Using Multi-Temporal Sentinel-2 Data. Remote Sensing (2019) 11:929.

Hoscilo A., Lewandowska A., Ziółkowski D., Stereńczak K., Lisańczuk M., Schmullius C., Pathe C. (2018) Forest Aboveground Biomass Estimation Using a Combination of Sentinel-1 and Sentinel-2 Data. In: IEEE International Geoscience & Remote Sensing Symposium (IGARSS2018) 22-27.07.2018, Valencia, Spain.

Hościło A., Mirończuk A. Europejski Program Obserwacji Ziemi Copernicus źródłem danych do ocen odziaływania na środowisko. (2016a) Poznań: M. Nowak - Wydawnictwo Naukowe UAM.

Hościło A., Mirończuk A. Europejski Program Obserwacji Ziemi Copernicus źródłem danych do ocen odziaływania na środowisko, rozdział w monografii: GIS i dane przestrzenne w ocenach oddziaływania na środowisko - podręcznik dobrych praktyk, M. Nowak. (2016b) Poznań: Wydawnictwo Naukowe UAM.

Hościło A., Mirończuk A., Lewandowska A. Określenie rzeczywistej powierzchni lasów w Polsce na podstawie dostępnych danych przestrzennych. Sylwan (2016) 160:627−634.

Hoscilo A., Tomaszewska M. CORINE Land Cover 2012 - 4th CLC inventory completed in Poland. Geoinformation Issues (2015) 1:49-58.

Hoscilo A., Turlej K. Use of satellite data for monitoring fire events in Poland. In proceedings of the IEEE Geoscience and Remote Sensing (IGARSS2014) (2014):828-831.

Hoscilo A., Ziolkowski D., Lewandowska A., Sterenczak K., Bochenek Z., Bartold M. (2016) Synergistic use of SAR and optical datasets for forest biomass retrieval and characterization of forests in temperate zone - a national case study Poland. In: 7th ForestSAT 2016 Symposium 14 - 18.11.2016, Santiago, Chile.

Houghton R.A., House J.I., Pongratz J., van der Werf G.R., DeFries R.S., Hansen M.C., Le Quéré C., i in. Carbon emissions from land use and land-cover change. Biogeosciences (2012) 9:5125-5142.

Immitzer M., Vuolo F., Atzberger C. First Experience with Sentinel-2 Data for Crop and Tree Species Classifications in Central Europe. Remote Sensing (2016) 8:166.

IPCC. (2018) Global Warming of 1.5°C, an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strang.thening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. In: Special Report on the Ocean and Cryosphere in a Changing Climate, and Climate Change and Land--V. Masson-Delmotte P.Z., H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.), ed. Geneva, Switzerland: World Meteorological Organization.

Isuhuaylas L.A.V., Hirata Y., Santos L.C.V., Torobeo N.S. Natural Forest Mapping in the Andes (Peru): A Comparison of the Performance of Machine-Learning Algorithms. Remote Sensing (2018) 10.

Jabłoński M. Powierzchnia gruntów leśnych – przyczyny zmian i spójność źródeł danych. Wiadomości Statystyczne (2015) 11:54-68.

Jabłoński M., Mionskowski M., Budniak P. Forest area in Poland based on national forest inventory. Sylwan (2018) 162:365−372.

Ji W., Wang L. Phenology-guided saltcedar (Tamarix spp.) mapping using Landsat TM images in western U.S. Remote Sensing of Environment (2016) 173:29-38.

Kałuski M., Hościło A., Gurdak R. Accuracy assessment of the Copernicus Buildings Height 2012 layer based on the city of Warsaw. Geoinformation Issues (2018) 10.

Kaufman Y.J., Justice C., Flynn O.L., Kandall J., Prins E., Ward D.E., Menzel P., i in. Monitoring global fires from EOS-MODIS. Journal of Geophisical Research (1998) 103:32,215 - 232,239.

Kolecka N., Kozak J., Kaim D., Dobosz M., Ginzler C., Psomas A. Mapping Secondary Forest Succession on Abandoned Agricultural Land with LiDAR Point Clouds and Terrestrial Photography. Remote Sensing (2015) 7:8300−8322.

Kolecka N., Kozak J., Kaim D., Dobosz M., Ostafin K., Ostapowicz K., Wezyk P., i in. Understanding farmland abandonment in the Polish Carpathians. Applied Geography (2018) 88:62-72.

Liu Y.A., Gong W.S., Hu X.Y., Gong J.Y. Forest Type Identification with Random Forest Using Sentinel-1A, Sentinel-2A, Multi-Temporal Landsat-8 and DEM Data. Remote Sensing (2018) 10:1-22.

Mirończuk A., Hościło A. Mapping tree cover with Sentinel-2 data using the Support Vector Machines (SVM). Geoinformation Issues (2017) 9:27-38.

Mirończuk A., Hościło A., Leszczyńska A. Copernicus źródłem informacji o dominującym typie drzewostanu w Polsce – ocena dokładność krajowej warstwy szczegółowej Dominat Leaf Type (DLT). (2019a) w przygotowaniu.

Mirończuk A., Hościło A., Lewandowska A. (2019b) Monitoring of forest damage in the Tatra Mountains using a time series of Sentinel-2 data. In: ESA living Planet Symposium--ESA, ed. 13-17.05.2019, Mediolan, Włochy: https://lps19.esa.int/NikalWebsitePortal/living-planet-symposium-2019/lps19/Speaker#.

Mountrakis G., Im J., Ogole C. Support vector machines in remote sensing: A review. ISPRS Journal of Photogrammetry and Remote Sensing (2011) 66:247-259.

Naudts K., Chen Y., McGrath M.J., Ryder J., Valade A., Otto J., Luyssaert S. Europe's forest management did not mitigate climate warming. Science (2016) 351:597-600.

Pelletier C., Valero S., Inglada J., Champion N., Dedieu G. Assessing the robustness of Random Forests to map land cover with high resolution satellite image time series over large areas. Remote Sensing of Environment (2016) 187:156-168.

Persson M., Lindberg E., Reese H. Tree Species Classification with Multi-Temporal Sentinel-2 Data. Remote Sensing (2018) 10:1-17.

Rodriguez-Galiano V.F., Ghimire B., Rogan J., Chica-Olmo M., Rigol-Sanchez J.P. An assessment of the effectiveness of a random forest classifier for land-cover classification. ISPRS Journal of Photogrammetry and Remote Sensing (2012) 67:93-104.

Rodríguez-Veiga P., Quegan S., Carreiras J., Persson H.J., Fransson J.E.S., Hoscilo A., Ziolkowski D., i in. Forest biomass retrieval approaches from earth observation in different biomess. International Journal of Applied Earth Observation and Geoinformation (2019) 77.

Stoffels J., Hill J., Sachtleber T., Mader S., Buddenbaum H., Stern O., Langshausen J., i in. Satellite-Based Derivation of High-Resolution Forest Information Layers for Operational Forest Management. Forests (2015) 6:1982-2013.

Thorn S., Bässler C., Svoboda M., J. M. Effects of natural disturbances and salvage logging on biodiversity - Lessons from the Bohemian Forest. Forest Ecology and Management (2016) 388:113−119.

UNFCCC. (2008) Kyoto Protocol Reference Manual on Accounting of Emissions and Assigned Amounts--UNFCCC, ed. Available online: https://unfccc.int/resource/docs/publications/08_unfccc_kp_ref_manual.pdf.

Waser L.T., Küchler M., Jütte K., Stampfer T. Evaluating the Potential of WorldView-2 Data to Classify Tree Species and Different Levels of Ash Mortality. Remote Sensing (2014) 6:4515-4545.

Wessel M., Brandmeier M., Tiede D. Evaluation of Different Machine Learning Algorithms for Scalable Classification of Tree Types and Tree Species Based on Sentinel-2 Data. Remote Sensing (2018) 10:2-21.

Wittke S., Yu X., Karjalainen M., Hyyppä J., Puttonen E. Comparison of two-dimensional multitemporal Sentinel-2 data with three-dimensional remote sensing data sources for forest inventory parameter estimation over a boreal forest. International Journal of Applied Earth Observation and Geoinformation (2019) 76:167-178.

Wooster M.J., Roberts G., Perry G.L.W., Kaufman Y.J. Retrieval of biomass combustion rates and totals from fire radiativepower observations: FRP derivation and calibration relationships between biomass consumption and fire radiative energy release. Journal of Geophisical Research (2005) 110.

Zhu X., Liu D. Accurate mapping of forest types using dense seasonal Landsat time-series,. ISPRS Journal of Photogrammetry and Remote Sensing (2014) 96:1-11.

Ziemblicki M.H. Uwarunkowania prawne nadzoru nad lasami niestanowiącymi własności Skarbu Państwa / Legal conditions of supervision over private forests Białostockie Studia Prawnicze (2015):297-305.

Żmihorski M. The effect of windthrow and its management on breeding bird communities in a managed forest. Biodiversity & Conservation (2010) 19:1871–1882.

Warsaw, 26.04.2019

Agata Hościło