4th International Workshop
on Uncertainty in Atmospheric Emissions

7-9 October 2015, Krakow, Poland

PROCEEDINGS

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About the Workshop

The assessment of greenhouse gases and air pollutants (indirect GHGs) emitted to and removed from the atmosphere is high on the political and scientific agendas. Building on the UN climate process, the international community strives to address the long-term challenge of climate change collectively and comprehensively, and to take concrete and timely action that proves sustainable and robust in the future. Under the umbrella of the UN Framework Convention on Climate Change, mainly developed country parties to the Convention have, since the mid-1990s, published annual or periodic inventories of emissions and removals, and continued to do so after the Kyoto Protocol to the Convention ceased in 2012. Policymakers use these inventories to develop strategies and policies for emission reductions and to track the progress of those strategies and policies. Where formal commitments to limit emissions exist, regulatory agencies and corporations rely on emission inventories to establish compliance records.

However, as increasing international concern and cooperation aim at policy-oriented solutions to the climate change problem, a number of issues circulating around uncertainty have come to the fore, which were undervalued or left unmentioned at the time of the Kyoto Protocol but require adequate recognition under a workable and legislated successor agreement. Accounting and verification of emissions in space and time, compliance with emission reduction commitments, risk of exceeding future temperature targets, evaluating effects of mitigation versus adaptation versus intensity of induced impacts at home and elsewhere, and accounting of traded emission permits are to name but a few.

The *4th International Workshop on Uncertainty in Atmospheric Emissions* is jointly organized by the *Systems Research Institute of the Polish Academy of Sciences*, the Austrian-based *International Institute for Applied Systems Analysis*, and the *Lviv Polytechnic National University*. The 4th Uncertainty Workshop follows up and expands on the scope of the earlier Uncertainty Workshops – the *1st Workshop* in 2004 in Warsaw, Poland; the *2nd Workshop* in 2007 in Laxenburg, Austria; and the *3rd Workshop* in 2010 in Lviv, Ukraine.

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Forest map and its uncertainty as an important input for carbon sink estimation for Poland and Ukraine

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Abstract

Improving knowledge on the land cover and forest ecosystems is of a high importance for carrying out spatial inventories of emissions and removals in forestry as the best way to achieve reliable results of forest carbon account. The region of the study is the territory of Poland and Ukraine, covering a substantial part of European diversity of natural landscapes. In addition, Ukraine and Poland have a high potential to sequester carbon through afforestation. The accuracy of available forest maps varies considerably over space. We have applied the method of geographically weighted regression to generate a hybrid forest map for Poland and Ukraine. This method predicts land cover types based on crowdsourced data obtained from the Geo-Wiki project, and land cover/forest cover products derived from remote sensing. The hybrid forest cover was found to be more accurate than the individual forest maps extracted from global remote sensing land cover products.

Keywords: forest cover, carbon sink, remote sensing.

1. Introduction

Improving knowledge on the land cover and forest ecosystems is of a high importance for carrying out spatial inventories of emissions and removals in forestry as the best way to achieve reliable results of forest carbon account. Not every country provide a full information on forest area and forest spatial distribution, including distribution of tree species and their age [1]. The reasons for this are different, e.g. absence of forest inventory in the territories that do not belong to forest enterprises; unavailability of data about private forests; obsolete data of forest inventories; existence of territories with rapid changes of forest cover, e.g. encroachment of forests in abandoned agricultural land. Providing an accurate data on forest spatial distribution is one of the steps towards an appropriate estimation of full carbon account [2]. One of the ways to complement the forest data is involving remote sensing data in the estimation of forest area and forest parameters. In this study, we developed a new forest map at a resolution of 60 m by fusing available data derived from remote sensing.

The region of the study is the territory of Poland and Ukraine, covering a substantial part of East-European diversity of natural landscapes. Forest in Poland covers more than 30% of the total area of the country while Ukraine is a forest-poor country with less than 16%. This provides a contrasting set of countries for analysis. In addition, Ukraine and Poland have a high potential to sequester carbon through afforestation [3].

As input data we used a number of global land cover products as well as global forest maps that have become recently available. The accuracy of these maps varies considerably over space [4]. We have applied data fusion methods to combine available sources of forest allocation in order to produce a hybrid product of higher accuracy than any of the individual input maps. Particularly, we have applied the method of geographically weighted regression (GWR) to generate a hybrid forest (raster) map for Poland and Ukraine. This method predicts land cover types based on (1) crowdsourced data obtained from the Geo-Wiki project (http://geo-wiki.org/), which are assumed to be true, and (2) land cover/forest products derived from remote sensing (e.g., LANDSAT-based Hansen's forest change, Globeland 30m, JAXA forest presence/absence). The year of reference of the input data is 2010.

The paper includes methodology description and analysis of the results.

2. Methodology

2.1 Input layers

Recently a number of remote sensing products has emerged. The overall trend has been towards higher spatial resolution such as the 30-meter resolution maps of percentage forest cover, forest cover gain and loss by Hansen [5], and the 30m Globeland product [6]. These maps were developed from Landsat high resolution satellite imagery, which has recently become freely available [7]. Another example is a new JAXA forest/non forest map at a resolution of 25m [8]. A resolution of other available remote sensing datasets is much higher, e.g. Globcover 2009 with a resolution 300m [9], MODIS vegetation continuous fields 250m [10], etc. Disaggregation of the medium resolution products increases uncertainty of forest distribution in space. Therefore Hansen's tree cover, Globeland 30m and JAXA forest/non-forest products have been chosen to develop a hybrid forest map at a resolution of 60m for the year 2010. The short description of the input products is below.

Landsat-based tree cover 2000 by Hansen is a global forest cover change product for the years 2000–2012 with a spatial resolution of 30 m [5]. The product is based on Landsat imagery and has three components: forest cover 2000, forest gain 2000–2012 and annual forest loss. We created a forest map for 2010 by combining the data from three levels: a basis – forest map 2000 – plus forest gain and minus forest loss for the time period of 2000-2010.

The 30m Globeland product 2000/2010 is provided by National Geomatics Center of China [11]. It is based on Landsat imagery with the combination of land resource information and HJ-1 satellite image. The product is freely available and comprises ten land cover classes including forest. We extracted the forest mask from Globeland 30m 2010 for Poland and Ukraine.

Japan Aerospace Exploration Agency (JAXA) has produced the 25 m forest/non-forest map based on imagery from the Phased Array type L-band Synthetic Aperture Radar (PALSAR) aboard the Advanced Land Observing Satellite "DAICHI" (ALOS) [8]. The product is available also at a resolution of 10 m.

The three forest maps were aggregated to the resolution of 60m in order to minimize the spatial errors while comparing different grids. We then calculated the average percentage of forest cover in a 60m pixel for every product.

2.2 Reference data from Geo-wiki

Reference data on forest cover were collected through the Geo-Wiki project [12], which aims at validating, correcting and enhancing land cover products. Five forestry and remote sensing experts collected the data by visually estimating land cover visible in cells of a grid overlaid onto high resolution Google Earth imagery. Figure 1 illustrates the example of collecting forest data through a customised Geo-wiki application. The

60m grid was used as the basis for the output map. Our samples of training data and validating data were randomly generated in forest and non-forest areas.

Figure 1. A customised geo-wiki application for collecting forest cover data

The final training data set contains approximately 14 K and 6 K pixels of land cover information (presence/absence of forest) for Ukraine and Poland, respectively. The validation datasets include approximately 4 K and 2 K pixels for Ukraine and Poland, respectively.

2.3 Geographically weighted regression

To combine the three above land cover products and Geo-wiki training data on forest presence/absence, geographically weighted regression (GWR) is employed for development of forest cover map [13]. GWR estimates model parameters at each geographical location by using a kernel. In addition, the observations are weighted by distance, so those closer to the studied location have more influence on the parameter estimates.

The probability of forest presence was then estimated using logistic GWR where the probabilities of correspondence between the Geo-Wiki training data and the input layers were calculated as follows:

$$\log it\left(P(y_i=1)\right)=b_{0(u_i,v_i)}+b_{1(u_i,v_i)}x_{1(i,j)}+b_{2(u_i,v_i)}x_{1(i,j)}+\ldots+b_{n(u_i,v_i)}x_{n(i,j)}$$

where $P(y_i=1)$ is the probability of forest at each location i; *logit* is a logistic regression; (u_i,v_i) is the two-dimensional vector of location i; $b_{0(u_i,v_i)}$ is the interception term; $b_j, j=\overline{1,n}$ are coefficients of logistic regression model; $x_j, j=\overline{1,n}$ indicate the presence of forest cover by global land cover product j; n is a number of input datasets.and n is the number of input datasets.

Maps of forest probabilities were converted to forest presence/absence maps by applying a threshold of 50%, following the example of the usage of logistic regression models in [14]. The hybrid forest map was developed in the R environment, which is a free statistical software with various geographical libraries.

3. Results

We developed a hybrid forest map for the year 2010 for Poland and Ukraine. It is a first forest map for those countries at a resolution of 60m. Figure 2 presents the forest distribution of Poland and Figure 3 corresponds to the forest distribution of Ukraine.

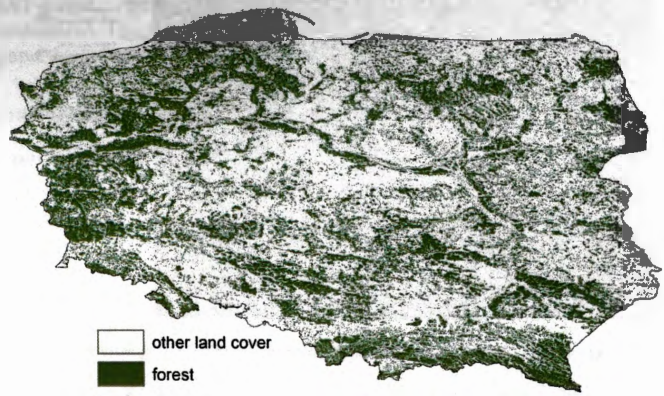

Figure 2. Forest cover map of Poland, 2010

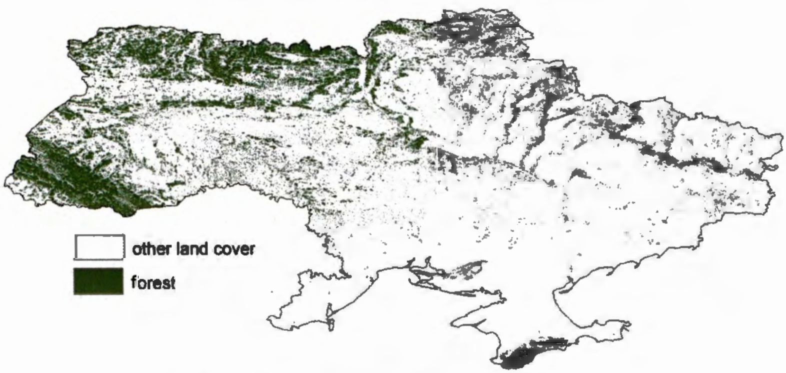

Figure 3. Forest cover map of Ukraine, 2010

The accuracy of the resultant map was assessed by using an independent validation dataset for Poland and Ukraine. Table 1 includes the estimated uncertainty, sensitivity and specificity of the hybrid forest map, and aggregated Hansen's tree cover, Globeland 30m and JAXA forest/non-forest maps. Sensitivity is calculated as the proportion of true positives, and specificity is calculated as the proportion of true negatives.

The hybrid forest maps are more accurate that the input layers. Globeland 30m has the lowest accuracy and, therefore, cannot be used for identification of forest changes during the period 2000-2010. Hansen's tree cover and JAXA forest/non-forest also need to be improved by the producers as they cannot be used for detection of forest changes in space neither.

Table 1. Accuracy, sensitivity and specificity of the hybrid forest map and the input

Forest maps	Ukraine			Poland		
	Accuracy %	Sensitivity %	Specificity %	Accuracy %	Sensitivity %	Specificity %
A hybrid map	90,1	91,0	87,0	91,2	95,6	86,1
Hansen's map	86,7	95,0	77,6	89,0	87,0	91,3
Globeland 30m	88,2	92,3	83,1	82,6	85,5	80,5
JAXA map	84,7	84,0	85,2	83,2	91,6	72,2

The total forest area from the hybrid maps has been found to be approximately 9.56 mln ha and 9.7 mln ha for Ukraine and Poland, respectively. In official statistics, Ukraine reports to have 9.57 mln ha of forest land [15]. Such a high consistency seems surprising taking into account that reliable inventory data is available only for 8.5 mln ha of forest. In addition, official Ukrainian reports do not account forest land on abandoned agricultural land and contain obsolete data about protective forests and shelterbelts on agricultural land, particularly in steppe and forest steppe zones of the country. These processes are revealed on regional level providing increase the forest area in the northern part and decrease – in the southern one. The simplified calculation allows us to conclude that the hybrid map estimates the total forest area in Ukraine with uncertainty in limits of 2-3%, while regional estimates are more uncertain and likely less biased than forest inventory data.

According to the official forest reports of Poland, the country has 9.2 mln ha of forest land [16]. Taking into account that the hybrid map also covers the settlement areas covered by trees (e.g., parks and garden), this also could be a reason of some, relatively small discrepancy in our estimates and official data of forest areas in Poland and Ukraine.

4. Conclusions

The hybrid forest cover for Poland and Ukraine was found to be more accurate than the individual forest maps extracted from global remote sensing products. Overall, these estimates are rather close to the countries' official statistics taken into account some inconsistency in the forest definitions used by official statistics and by this study. The two major current processes of rapid changes of forest area of Ukraine are: 1) restoration of forest vegetation on abandoned agricultural land in the forest zone and 2) impoverishment of protective forests in the southern part of the country. These processes provide different impacts on the change of forest area are not satisfactory reflected by the official forest inventory.

For countries that do not currently have an accurate enough land cover data, the presented methodology provides an opportunity to develop forest maps that can be further used in different national, regional and global applications, including accounting and verification of emissions of greenhouse gases in space and time. This study shows that uncertainties of such maps do not exceed uncertainties of other components of carbon budget of forest ecosystems.

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