The use of satellite images to forecast agricultural production

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ABSTRACT

In the first part of the speech, the results of cooperation between the Department of Agriculture in the Central Statistical Office and the Institute of Geodesy and Cartography in Warsaw will be presented. The presentation will be focused on the possibility of satellite image use to forecast agricultural production. A short description of NOAA AVHRR satellite images will be presented. Furthermore, a satellite imagery receiving system, which consists of a parabolic antenna with the diameter of 1.2 m, a signal receiver and specialised software enabling data recording, will be described. The software provides automatic operation of the station, namely, recording of images as soon as the NOAA satellite comes within the range sufficient for receiving signals, designated by the minimum "view" angle of the satellite. It also provides up-to-date information on the position of the satellite in relation to the area of Poland, as well as the time of the nearest recording. During recording, it allows for "viewing" the image in 2 radiation ranges - near-infrared and thermal infrared. While speech, a system of crops condition estimation using comparative maps will also be discussed. The final products in the Crop Yield Assessment System are comparative maps of the NDVI value as compared to an average year and the previous year. In order to generate these products, a specialised module has been developed as part of the ArcMap software. This module, using software functions, enables execution of creation of ten-day compositions from the corrected images of the NDVI and creation of comparative maps of the NDVI distribution in comparison to an average year and the previous year. These maps are generated on a 1 km2 grid and averaged to voivodships (NTS 2) and in selected voivodships to poviats (NTS 4).

In the second part of the paper, it will be presented a comparison of yield estimation for a few crops, carried out by experts for field crop production with the data obtained from maps of NDVI indicator distribution. It will be presented comparing the imaging index NDVI with data obtained from estimates developed in the Central Statistical Office, Agriculture Department for 2015, as a model to represent optimal weather conditions for crop production from wheat and all cereals. The map of agricultural drought in Poland in 2015 will also be presented.

Keywords: satellite imagery, yield estimation, harvest statistics

1. Introduction

The role of the official statistics is delivering high quality data concerning broad variety of topics. The very important domain of the official statistics is agriculture as a part of wider classification of land cover or use. Because of its characteristics such as large area or huge spatial and temporal variability, agriculture is predestined to survey techniques that can globally survey areas of whole countries or regions delivering data in short time intervals during a year.

Therefore, the satellite imagery can be successfully used for agriculture and different land cover/use classifications. In agriculture, the most common applications of satellite images can be attributed to crop area estimation, plant production estimation / prediction as well as measuring plant growth conditions or effects of extreme weather conditions (e.g. droughts, floods, frost damages). The above mentioned examples do not exhaust possibilities of using satellite images. However, for the needs of this publication only application in estimation of agricultural production would be described.

The satellite images are usually classified as Big Data. In many projects launched by EUROSTAT, use of Big Data sources in combination with existing official statistical data is studied to improve current statistics and create new statistics in various statistical domains, namely, agriculture. The more important running projects belonging to multisource statistics, where the satellite data are investigated, are following:

- ESS ADMIN VIP - use of administrative data in statistics including issues related to multisource statistics
- ESSNET ADMIN - quality of multisource statistics
- ESSNET BIG DATA - matching administrative data i.e. LPIS with big data i.e. satellite imagery in agriculture statistics

The Central Statistical Office cooperates closely with the Institute of Geodesy and Cartography in Warsaw, which provides results of NDVI for poviats (NTS 4) as well as production forecasts for cereal crops for voivodships (NTS 2). This multiannual cooperation yielded with the systematically updated data base and the sustainable model of vegetation assessment.

2. Materials and methods

<u>Yield estimates of Central Statistical Office</u>

The Central statistical Office collects information concerning areas, yield and harvest from different sources. The basic information about crop areas comes from farm surveys (e.g. Farm Structure Survey) or administrative data like IACS (Integrated Administration and Control System). Information about plant production is obtained from field experts in each gmina (NTS 5). The estimated yields are representative for voivodships (NTS 2). Furthermore, the voivodship and country yield and harvest estimates are reviewed by regional and country experts. In estimation of harvest also market data are taken into account. The estimates are published three times a year starting from the end of July.

<u>Method of satellite imagery processing in the Institute of Geodesy and Cartography</u>

One of the first systems for monitoring of agricultural areas CCAP (Crop Condition Assessment Program) was created by the Canadian Centre for Remote Sensing CCRS. This programme was based on the use of satellite images taken every ten days by the NOAA AVHRR (Advanced Very High Resolution Radiometer) for determination of the development state of crops. The technology developed by the CCRS was implemented in 1996 in the Institute of Geodesy and Cartography in Warsaw, see fig. 1.. This technology consists of the following stages:

- recording of satellite images acquired by AVHRR scanners installed on the NOAA series satellites for the area of the entire country within the vegetation period of the cultivated plants,
- geometric and radiometric processing of the recorded images taken by the NOAA AVHRR,
- determination of the vegetation index - NDVI, on the basis of the radiation value recorded by the NOAA AVHRR scanner,
- creation of ten-day compositions for agricultural areas on the basis of daily images of the NDVI distribution,
- preparation of comparative maps of the NDVI distribution in comparison with an average year and with the previous year for particular ten-day periods of the vegetation season,
- determination of the process of changes in the value of the NDVI describing the development of cultivated plants within the vegetation season.

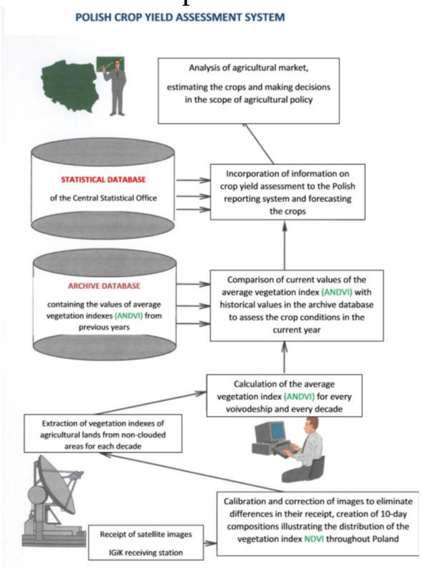

Figure 1: *The diagram of the crop yield assessment system operation.*

Satellites launched by the American agency NOAA are equipped with several instruments for environment research. An instrument used for acquiring information about reflection of radiation from land and about surface temperature is the AVHHR scanner (Advanced Very High Resolution Radiometer). The latest version of this instrument (AVHRR3) can register radiation in 6 scanning ranges:

channel 1 - 0.58 - 0.68 μm
channel 2 - 0.72 - 1.0 μm
channel 3A - 1.58 - 1.64 μm
channel 3B - 3.55 - 3.93 μm
channel 4 - 10.3 - 11.3 μm
channel 5 - 11.5 - 12.5 μm

The first two channels provide information about reflection of radiation in the full-visible and near-infrared range. Channels 3A and 3B cover medium infrared range, and channels 4 and 5 (thermal infrared) provide information about land temperature.

Images recorded by the NOAA AVHRR scanner cover an area of ca. 2400 x 2400 km. Depending on the location of the orbit in relation to the receiving station, they may be received 2 - 4 times per day. For the purpose of monitoring of the area surface, images recorded in early afternoon (12:30 a.m. - 3:00 p.m.) are most often used. Field resolution of images in the nadir point is 1.1 x 1.1 km. The images are transmitted to the data receiving station in the HRPT format (High Resolution Picture Transmission) - it is the basic transmission format; they can also be received in the LAC format (Local Area Coverage). "Raw" images recorded by the receiving station require specialised software in order to process them to a state enabling environment condition analysis.

The receipt system consists of a parabolic antenna with the diameter of 1.2 m, a signal receiver and specialised software enabling data recording. The software provides automatic operation of the station, namely recording of images as soon as the NOAA satellite comes within the range sufficient for receiving signals, designated by the minimum "view" angle of the satellite. It also provides up-to-date information on the position of the satellite in relation to the area of Poland, as well as the time of the nearest recording, and during recording it allows for "viewing" the image in 2 radiation ranges - near-infrared and thermal infrared. The images recorded in the HRPT format are saved in the relevant system folder connected to the data receiving software, and then transmitted to the image processing system for the satellite images taken by the NOAA AVHRR.

Currently, for processing of satellite images taken by the NOAA AVHRR, the Institute of Geodesy and Cartography uses specialized module developed as part of the Chips software for Windows. This module covers full processing of data in 5 stages:

- import of the image in the HRPT format to the format of the software, along with analysis of image quality and extraction of information about orbit parameters, used in the subsequent data geometrisation,
- interactive geometric adjustment of the "raw" satellite image taken by the NOAA AVHRR to the reference picture,
- rectification of the image to a specified map projection (Albers projection), as well as to defined dimensions (700 x 700 km),
- radiometric calibration of the image in order to obtain pictures of albedo distribution in channels 1 and 2 and radiation temperature in channels 4 and 5,
- establishment of derivative products - a picture of distribution of the Normalised Difference Vegetation Index (NDVI) and a picture of temperature distribution of the area surface.

The final product of the module of the NOAA AVHRR Chips software for Windows is a set of geometrically adjusted and radio-metrically calibrated images in channels 1 - 5 of the AVHRR scanner, as well as derivative products. The data are prepared in the export format for use in the final stage of the Crop Yield Assessment System operation.

The final products in the Crop Yield Assessment System are comparative maps of the NDVI value as compared to an average year and the previous year. In order to generate these products, a specialised module has been prepared as part of the ArcMap software. This module, using software functions, enables execution of the following stages of works:

- atmospheric correction of daily images taken by the NOAA AVHRR in channels 1 and 2,
- creation of ten-day compositions from the corrected images of the NDVI,
- determination of agricultural areas of Poland by means of a mask created on the basis of the land cover map, drawn up under the CORINE Land Cover Programme,
- determination of threshold values of cloud cover and determination of ten-day composition unaffected by cloud cover for agricultural areas of the country,

- creation of comparative maps of the NDVI distribution in comparison, to an average year (designated on the basis of the NDVI value from 1992 - 2008) and to the previous year

These maps are generated on a 1 km2 grid and averaged to provinces. Information on the condition of crops is expressed by the relation of the NDVI in the current ten-day period to the value of this index in the same ten-day period of an average year or the previous year.

Comparative maps are supplied in ten-day intervals throughout the crops vegetation period (1st April - 30th September) to the Central Statistical Office, Department of Agriculture. On the basis of information from subsequent ten-day periods, charts are also created presenting changes in the NDVI within the vegetation season, as well as comparisons of comparative maps for the whole vegetation season. These products are supplied to the Department of Agriculture of the Central Statistical Office as part of the annual reports on the consecutive stages of the works.

3. Results and discussion

The monitoring of vegetation is expressed by indicator NDVI, which can be observed during the season. The seasonal differences are attributed to plant growth cycle as it can be presented in fig. 2. The interregional differences can be also noticed because of different cropping schemes and agricultural specialisation as well as climatic conditions.

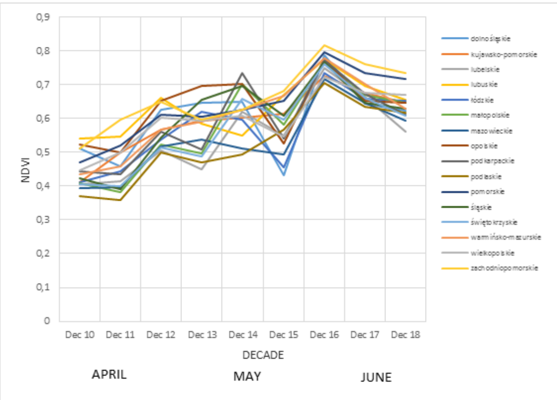

Figure 2: *NDVI changes during the first half of the vegetation period in 2015 for the different NTS2 regions (voivodships) of Poland.*

The NDVI values can compared with the same period of the previous year or an average year for a chosen region. In fig. 3, the regional differences (for NTS 4 – poviats) for June 2016 in comparison with June 2015 have been presented. Weaker vegetation (pink colour) is visible for the south eastern, central and north western Poland, which can be attributed to effects of drought in the second half of 2015 and majority of the first half of 2016.

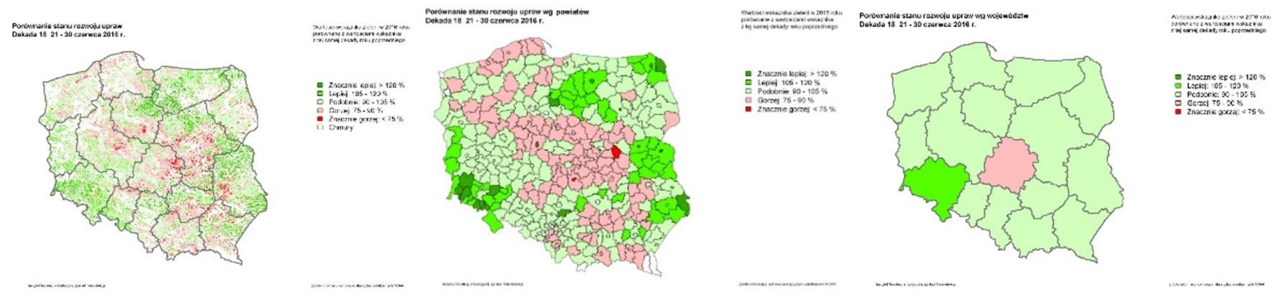

Figure 3: *Comparison of NDVI values of June 2016 with NDVI values in 2015. Data are presented for 1 square km grids, for NTS 4 regions and generalised for NTS 2 regions.*

Nevertheless, in the very south western region the vegetation is much better developed that a year ago. The analysis of the generalised and grid images shows huge decrease of details. However, the selection of agricultural areas helps to separate them from the other land cover classes.

The additional information from satellite imagery interpretation can be detection and determination of dangerous weather conditions or disasters. In agriculture, such disastrous situation can happened due to droughts, floods, hurricanes, freezing. Fig. 4 presents assessment of droughts prepared by Institute of Geodesy and Cartography in 2015. The intensity of red colour indicates drought in August 2015. The drought maps are very important for yield and harvest estimates as well as for farmers, agricultural advisors, administration or can be used by insurance companies.

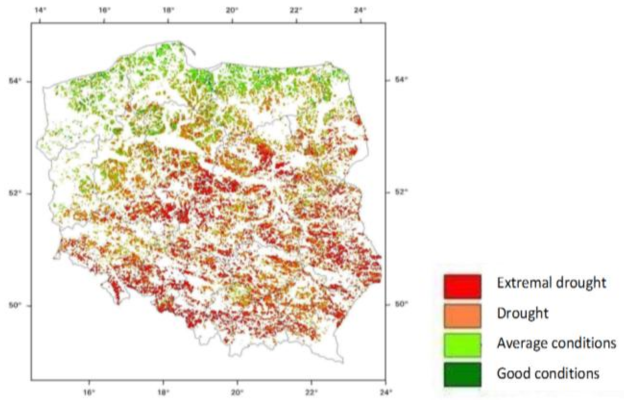

Figure 4: *The drought in August 2015 in Poland.*

The analysis of NDVI is a very helpful tool to assess the development of crop plants, which is ancillary to yield and harvest estimates. However, this indicator cannot be directly referred to yield estimates because the other factors such as start of vegetation period in a given year have to be considered. This issue is very important in terms of climate changes, when the vegetation period can start earlier resulting in earlier harvest and shifting NDVI values in a given year.

In the Central Statistical Office, the basis for the yields and harvest estimates are estimates of regional experts working on areas of gminas (NTS 5). Thus, about 2500 estimates are prepared and compiled for whole Poland each year. Simultaneously, data from modelling based on satellite imagery are delivered by the Institute of Geodesy and Cartography. The Fig. 6 presents the yield estimated for wheat in 2016. The yields are generalised for NTS 2, which is the standard grouping for official statistics. Data from satellite imagery interpretation are ancillary to yield and harvests estimates prepared by Central Statistical Office. In 2016, the modelling based on satellite images was applied for whole Poland for the first time. Thus, assessment of this data is still ongoing.

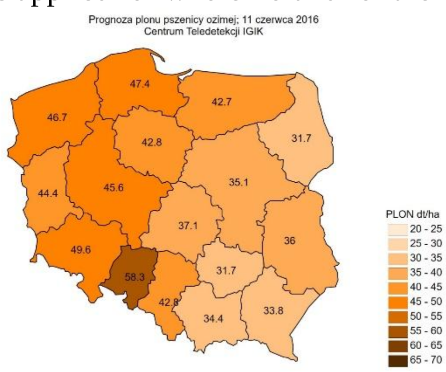

Figure 5: *The wheat yield estimates (dt/ha) for NTS2 regions in Poland in 2016.*

In 2015, the yield and harvests estimates based on modelling were studied in four NTS 2 regions (voivoships: dolnośląskie, warmińsko-mazurskie, wielkopolskie, zachodniopomorskie). The results were compared with the official data based i.e. on expert estimates, what was illustrated in Tab. 1.. The similar data were obtained also for all cereals.

Table 1: *Title of the table* (above the table, 12 pt italics, left-justified)

Voivodship (NTS 2)	Estimated yields (dt/ha)		Yield difference	
	Satellite	Statistical	dt/ha	%
DOLNOŚLĄSKIE	48,7	53,0	4,3	108,8
WARMIŃSKO-MAZURSKIE	43,3	50,9	7,6	117,6
WIELKOPOLSKIE	44,1	48,9	4,8	110,9
ZACHODNIOPOMORSKIE	46,1	59,2	13,1	128,4

The comparison shows that the yields and in consequence harvests are underestimated by the models based on satellite data. The above mentioned results cover only a few regions. The explanation of the differences could be attributed to use of long time series with yield low estimates. In recent years, the yield increase is being noticed due to development of highly specialised agricultural holdings and farm modernisation. The further validation of the results from interpretation of satellite imagery would be continued in 2016 for the whole territory of Poland. In coming years it is planned to switch to the satellite technics and modelling of harvest estimates as the basic source of information in this domain.

The experiences with satellite imagery interpretation show a huge potential for use in agricultural statistics. The vegetation monitoring and yield estimation are good examples of practical applications. Furthermore, the extremely important issue for agriculture statistics is assessment of crop area. The need for pilot studies and thematic project appears especially in recent years, when access to high resolution images has increased due to COPERNICUS or LANDSAT programmes. The official statistics is tapping in these new data sources but appropriate validations and methodological as well as quality review has to be carried out. The new initiatives of EUROSTAT concerning big and administrative data projects are good examples of such trend.