THE USE OF MODIS DATA IN SOUTHERN RUSSIA FOR CROP ACREAGE ESTIMATIONS AND INTER-COMPARISON OF RESULTS FROM VARIOUS CROP ACREAGE ESTIMATION METHODS

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ABSTRACT:

The first part of this paper presents a methodology on crop acreage estimations using the MODIS 16-day composite NDVI product. Particular emphasis is placed on a good quality crop mask and a good quality validation dataset. A novel approach which is based on the sampling of pure fields has been developed. The novel approach has been tested in previous work using a traditional maximum likelihood classification for 5 different crops. This novel approach has been further developed in this paper by applying a rule based approach which allows the estimation of winter wheat acreage in the study region. The advantage of such an approach is its simplicity, reasonable dataset input requirements and its potentially good forecasting capabilities. Training and rules are based on the year 2002. Results from this approach are shown together with an inter-comparison study which covers the second part of this paper.

An inter-comparison study as part of the GEOLAND project in the Observatory for Food Monitoring (OFM) was carried out. In order to study the capabilities of the different methods to estimate crop acreage 2 study areas were chosen, Belgium and the South-West of Russia. 3 crop types namely winter crops, maize and sugarbeet /potatoes were compared for Belgium for the year 2003 from the partners Infoterra France (ITF) and Vito. For the Russian test site, a common study area was defined for all 3 partners (Vito, ITF and JRC) which includes 6 Sub-Oblast administrative regions (districts) and winter crops were chosen as the common crop type. An extended area (22 districts) was defined for the 2 partners Vito and JRC. For the common test sites differences of the acreage estimates are highlighted, absolute errors and root mean square errors are examined and the significant differences of the datasets are explored.

1. INTRODUCTION

Recent developments in remote sensing technology, in particular improved spatial and temporal resolution, open new possibilities for estimating crop acreage over larger areas. Remotely sensed data allow the estimation of crop acreage statistics independently of sub-national survey statistics. This work focuses on the use of MODIS data acquired in 2001/2002 and 2004/2005 over the Rostov Oblast in Russia, by the Azov Sea. The region is characterized by large agricultural fields of around 75 hectares in average. The pure pixel sampling approach is a novel approach and uses segments derived from high resolution images in combination with coarser resolution MODIS data. This method takes on the one hand advantage of the high spatial resolution of high resolution data (e.g. Landsat) and of the high temporal profile of Medium resolution data (e.g. MODIS). In the following sections we consecutively describe the selection of the MODIS product, its geolocation quality, the way the high quality crop mask was derived, and the pure pixel sampling approach. The following sections describe how the method was implemented using the MODIS products as input for the medium resolution data and Landsat as input for the high resolution data. In the second part of this paper an inter-comparison study of the different methods applied in the GEOLAND Observatory for Food Monitoring (OFM) is presented.

2. MATERIAL AND METHODS

2.1 The appropriate MODIS product and its geolocation

Since there are many different MODIS products, it is not easy to decide which one is best suited for crop acreage estimations. The different available products were compared and advantages and disadvantages were considered. Other studies, for example a study which focused on the detecting of clear cuts in Russia, have shown that the 250 meter product is superior to the 500 meter product when smaller areas have to be monitored (Stibig and Bucha, 2005). The MOD13 product has been identified as the most useful product as NDVI are available and no pre-processing and compositing is required. Other current studies also use this product for acreage estimations (see Lobell and Asner, 2006). The 16-days product is a Maximum Value Composite (MVC), which selects the least cloud-atmosphere contaminated pixel and also tends to select the closest near-nadir view (Huete et al., 2002).

In order to use the MODIS data for acreage estimations the geolocation accuracy is an essential issue. Whereas former sensors such as AVHRR were prone to a high geolocation error, the MODIS sensor has much better geolocation accuracy. According to Stroeve et. al. (2005) the MODIS geolocation accuracy is better than 150 m at the 99% confidence interval. Nevertheless in case the product is used for acreage estimations a distance of 150 meters can matters, even though fields can be up to two square kilometres. However, it has been found on a sample site that the intra-geolocation error between the MODIS images is quite low and therefore a systematic correction can be performed.

2.2 The crop mask based on high resolution images and a report with field data graphic files ration

A general problem for acreage estimations in different places of the world is the lack of data to separate the natural vegetation from the agricultural areas. Due to the fact that for example grassland can show a similar profile as certain crop types, a good quality crop mask is essential to avoid classifying the natural vegetation as a crop or vice versa. Therefore, in case a crop mask is available for the region under analysis it is of advantage. Even if data on crop distribution is published in reports and only available as graphic files a crop mask can be derived by geo-referencing the graphics file to the Landsat data. For example vector segments can be derived (e.g. from the e-cognition software, Baatz and Schäpe, 2000) and all those segments can be removed which do not coincide with fields on the geo-referenced graphic files.

2.3 Landsat Segmentation and pure pixel sampling approach (PPS)

The method of segmentation was applied as to obtain an image which could be used to remove unwanted mixed pixels between fields. The full segmentation algorithm is described in Baatz and Schäpe (2000) and implemented in the e-cognition commercial software. The segmentation was applied to a selection of bands (band 3,4,5) for 4 images of the ETM time series. The software allows the user to choose the segmentation size and specify whether more compact features should be preferred. After trying different settings, a relatively small segmentation size was selected to ensure that all fields were segmented. The disadvantage was that some of the larger fields were divided into up to 3 segments.

We applied a method which removed all those pixels which were located on the border of a segment (the delineating vector of the segment). This reduced the overall number of pixels by more than 80%. Since by the removal of those potentially mixed pixels we reduced the overall area, we needed an estimator to calculate the overall area of a certain crop. We used a simple proportional estimator (see equation 1) and derived the estimated overall winter crop area for each district. We refer to this method as pure pixel sampling approach.

$$NS_W = \frac{S_W}{S_A} * NS_A \qquad (1)$$

Where :
S_W = the number of pixels classified as the crop of interest
S_A = the number of all pixels which were sampled (pure pixels)
NS_A = all pixels found in the crop mask

In order to test the approach described above be applied it to the South-Western region of Russia the Oblast Rostov. It is located at the Asov Sea. When the Landsat image is segmented the borders between fields can be quite well captured. In a previous study we compared the pure pixel sampling approach with a hard classification. We applied a simple Maximum likelihood classification (Fritz et al, submitted). When undertaking the pure pixel sampling approach, the overall number of used pixels was reduced to around 16% of the total, but this still allowed to produce the confusion matrix. Whereas similar pattern as found in the other matrices evolve, the overall kappa coefficient is significantly better for the pure pixel sampling approach. Furthermore, the overall percentage RMSE of the official winter crop area was lower. Moreover, producers and users accuracy for winter crops improved which make this approach an attractive candidate for studies on the discrimination of different crops. It also allows to study other methods such as Neural Networks (NN) or rule based methods. We applied a rule-based method for the discrimination of winter crops from the others. These rules to discriminate winter crops from the rest is shown in Figure 1.

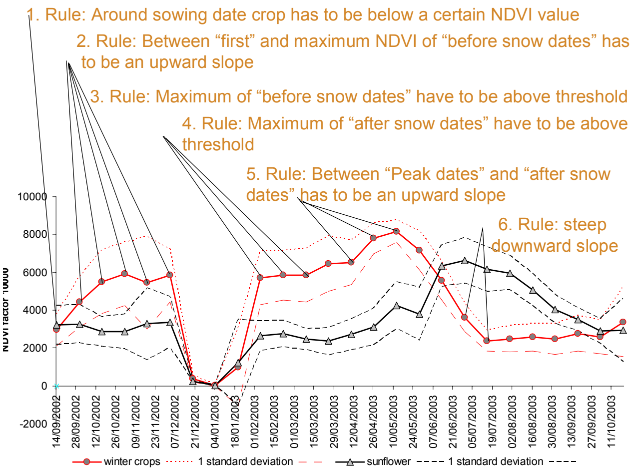

Figure 1: Six derived rules for the identification of winter crops

As it can be seen by applying the 6 rules, the different profiles of sunflower and winter crops can easily be distinguished. The profile of sunflower is used here as an example since it is the second cash crop in this area. The question remains where to define the thresholds which define the rules.

2.4 Standard approach

The crucial question for the rule based approach is how to define these rules. One objective way is to use a value which can be derived from a statistical analysis. Therefore we used 1 standard deviation of the different crops as a criteria to define our rules. For example in our example we see that winter crops in the sawing period have a low NDVI and define it for the first rule to be below 0.4 (with factor 10000 below 4000) and for the third rule that the maximum of the 16-day composites between the 28th of September and the 7th of December is higher than 0.4 (is higher than 4000). If all the 6 rules are fulfilled the crop qualifies for a winter crop. These rules are defined with the use of one standard deviation in the JRC standard approach. This approach of the use of one standard deviation is quite conservative and the maximum of a number of dates in a 16-day composite is expected to be quite stable over the years. However, the downside of this approach is that certain climate variations over years are not taken into account. Current research therefore focuses on a better way of defining these rules for example by using a field homogeneity index. This index is based on the homogeneity of crop pixels within the Landsat TM segments.

2.5 Approach which uses statistics from the same year for calibration

Instead of deriving the thresholds for the 6 rules from one standard deviation, the rules can be derived directly from statistical information which can be collected with the use of in-situ measurements and/or high resolution data. This means that for example in one area farm data could be collected earlier in the year or even a satellite image covering that area such as Landsat or Aster image of that year can be used to derived information on acreage in one sub-administrative unit. The rules are for this method defined by an exhaustive search where those 6 rules are used which minimise the RMSE for one sub-administrative unit. The exhaustive search is based on small incremental thresholds for each of the 6 rules. An optimal combination of the 6 rules is found based on information of one sub-administrative area. In our case study this means that the surrounding 5 sub-administrative regions could be estimated and the rules are derived from the smallest one. The method proved to be very accurate and is therefore presented in this study. It has to be however pointed out here that this method is using data which has not been available to the other partners (from the year 2005). It is therefore strictly speaking not part of the inter-comparison, which is based on data for the year 2005.

2.6 Discussion and conclusions on the pure pixel sampling approach

The described approach has shown that additional input data from high resolution Landsat data (freely available though: http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp) can be combined with information from the freely available MODIS dataset with a very good temporal coverage. The advantage is that the fields do hardly change over time and the segments can be used over a period of several years. Nevertheless, it has to be outlined here that the basic assumption was made that the proportion of pixels laying inside a segment is the same as the proportion of pixels laying on the border (segment vector) of two segments. This assumption can be made if there is no tendency to give preference to have certain crop types on smaller fields since only the pixels within bigger segments (fields) are considered. In areas with big fields and high proportions of cash crops these assumptions are valid. **Results of the pure sampling approach are presented in the next section which shows results of the acreage inter-comparison study for which this approach was used.**

3. RESULTS FROM VARIOUS CROP ACREAGE ESTIMATION METHODS

The three methods compared in this study use MR-LR data which have a high temporal resolution: SPOT-VEGETATION (VGT), MODIS and MERIS. VGT and MODIS have a near global coverage every day and MERIS every 2 days. The VGT sensor has a spatial resolution of 1 km in five channels, MODIS 250 meters in two channels and MERIS 300 meters in 16 channels. Pixels of MR-LR data are usually of a mixed nature and thus encompass several Land covers. A hard classification method assigns the pixel to the dominant class and therefore often under- or overestimates certain classes. All three partners use more advanced approaches with respect to the hard classification which can deal with mixed pixels. However, the methods have differences with respect to the used sensor, input data and approach. VITO uses a neural network (NN), ITF uses an inversion model and JRC a pure pixel sampling (PPS) approach to estimate class proportions. In this report, a comparison of the three methods is performed.

Acreage estimations were compared for two sites: Belgium and South-West Rostov (Russia). The inter-comparison is based on qualitative and quantitative measures. The qualitative assessment compares the methods with respect to a number of criteria (e.g. amount and cost of input data). The quantitative assessment is based on a number of criteria such as the root mean square error, mean absolute error, a significance test and the coefficient of determination.

In Belgium three crop groups were investigated for the year 2003: winter crops, maize and sugar beet/ potatoes. However, in this paper only 2 crops groups (maize and sugarbeets +potatoes) are presented since they represent the spectrum of differences between the 2 methods. Whereas for the sugarbeets/potatoes the 2 methods show no significant difference, a significant difference in accuracy ? and a high difference in performance of the 2 methods can be found for maize. For Belgium VITO and ITF provided area estimations for the three crop groups in 26 agro-statistical districts (= administrative unit).

In the second area of interest, the Rostov Oblast, winter crops were chosen as the crop of interest. The three partners provided area estimates for this region. Crop acreages were evaluated with respect to statistics available for six districts in the SW of the Oblast. Calibration of the methods was done for 2002 on the SW Rostov and acreage estimates were calculated for 2005 for the whole or SW part of the region.

3.1 Sugar beets / Potatoes in Belgium

Figure 2 illustrate that the inversion model (ITF) seems to overestimate in nearly all cases whereas this is not the case for the NN (VITO). However, in the districts Tournai, Hasselt and Diskmuide, a relatively high error can be noted for the NN, for MODIS as well as VGT. Even though overall the NN applied on VGT data performs best in terms of RMSE and MAE (see Table 2) there is no significant difference between the three methods (see results of T-test, Table 1).

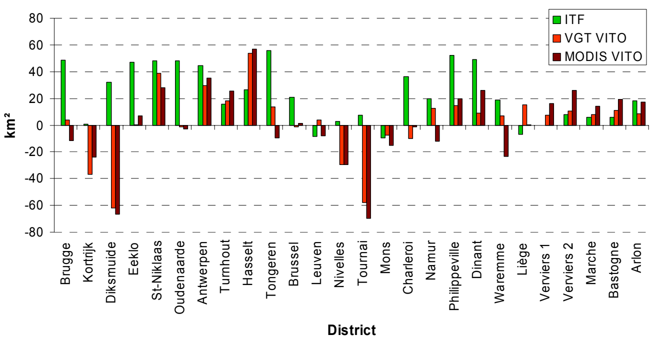

Figure 2: Difference for sugarbeets/potatoes acreage estimations compared with IACS database (Reference)

Table 1: Results of the T-test and rejection or approval of the null hypothesis (p-value = significance probability) for sugar beets/potatoes

	Students T-Value	p-value < 0.1	p-value <0.05
VGT - MERIS	0.218	No	No
MODIS – VGT	0.479	No	No
MODIS - MERIS	0.593	No	No

Table 2: RMSE (Root Mean Square Error) and Mean Absolute Error (MAE) for estimated sugar beet/potatoes acreages in Belgium for 2003 (in km²)

	ITF (MERIS)	VITO (VGT)	VITO (MODIS)
MAE	24.52	18.15	21.73
RMSE	31.15	25.48	28.57

3.2 Maize in Belgium

The Estimation Error of the methods is demonstrated in Figure 3. For maize, the NN (VITO) performs significantly better than the inversion model (ITF). Moreover, the NN calibrated with VGT data outperforms significantly the NN calibrated with MODIS data (Table 4). This phenomenon is surprising as the resolution of MODIS is much higher. Table 4 shows the t-values and the significance for the three methods

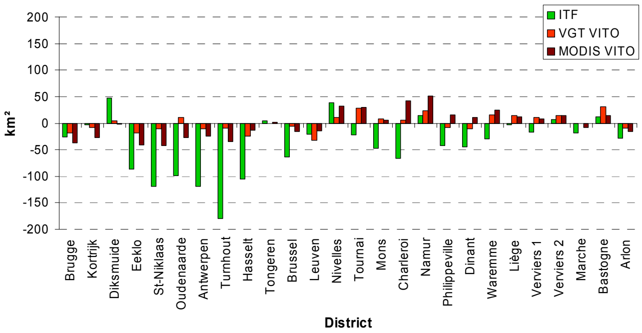

Figure 3: Difference for maize acreage estimations compared with IACS database (Reference)

Table 3: Results of the T-test and rejection or approval of the null hypothesis (p-value = significance probability) for maize

	Students T-Value	p-value < 0.1	p-value <0.05
VGT – MERIS	0.000	Yes	Yes
MODIS – VGT	0.010	Yes	Yes
MODIS - MERIS	0.005	Yes	Yes

Table 4: RMSE and MAE for estimated maize acreages in Belgium for 2003 (in km²)

	ITF (MERIS)	VITO (VGT)	VITO (MODIS)
MAE	48.61	13.43	21.84
RMSE	66.26	16.08	25.95

3.3 South-West Rostov

This study area was chosen as common test site for all three methods. Comparison of the three methods was performed for six districts in South West Rostov. These administrative units were taken since ITF and JRC needed a crop mask for application of their method. This mask was, however, only available for these districts. Data from the year 2002 was provided to the partners for calibration. Comparison of estimations was performed for 2005 (see Figure 4). The main difference between Rostov and Belgium is the size of the fields: the AOI is characterized by large fields, while in Belgium small fields are usually present.

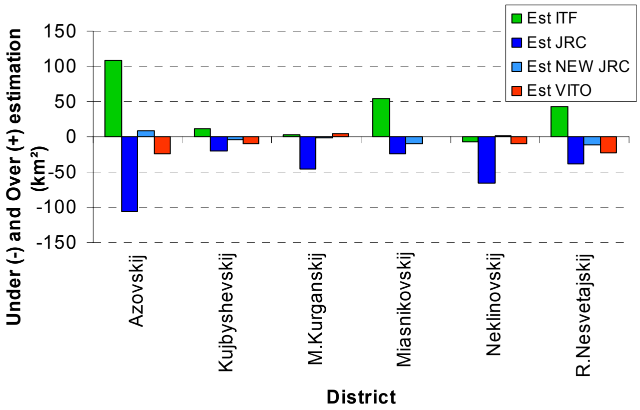

Figure 4: Acreage estimation error (km²); under (-) and overestimation (+) with statistics.

Another way of looking at the estimations is to assess the improvement of the estimations in 2005, compared with the statistical data from 2002 and to estimate the maximum detectable change in absolute terms. The maximum detectable change is simply calculated by the difference of the statistics for 2002 and 2005 in each district. The change for each RS method expressed in Figure 5 is the difference between the RS estimates for 2005 and the statistical data of 2002. Such an analysis is useful as statistical data from the year 2002 was given to the partners to train their model. VITO predicts detectable change in 4 districts well (in Azovski M. Kurganski, Miasinowskij and Neklinovski) whereas ITF predicts in 3 cases well Azovski, M.Kurganski and Neklinowski, though in the other 2 districts the prediction is worse than the statistics from the year 2002. The PPS (JRC standard method) which bases information on the year 2002 only predicts better for 2005 than the statistics in 2002 in the district Azovski (which experiences the most change). However, the PPS (JRC new statistical) method which is fed by information of one district performs very well and predicts winter crop acreage well in all 6 districts with a high accuracy. Since the analysis has been carried out in only 6 Districts none of the methods were significantly different. MAE and RMSE are given in Table 5.

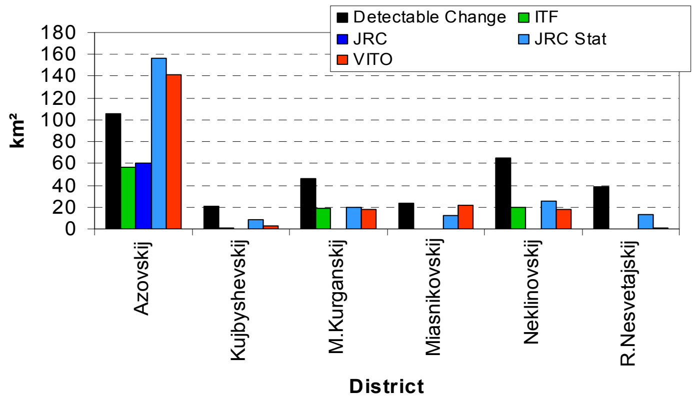

Figure 5: Districts in which the RS area estimation is better than the statistics for 2002 and area of winter crop difference between estimated figures in 2005 and statistics of 2002.If no bar is shown on the graph for a particular method the estimate is worse than the figure of the 2002 statistics

Table 5: MAE and RMSE for the 6 common districts

	JRC 2005	ITF 2005	VITO 2005	JRC new RS/stats
MAE	49.98	37.65	11.78	6.48
RMSE	57.65	52.69	14.75	7.62

4. CONCLUSIONS AND DISCUSSION

In order to undertake a quantitative comparison different error measures have been chosen. The performance was evaluated according to the Estimation Error (EE), the Mean Absolute Error (MAE) and the Root Mean Square Error (RMSE).

Following conclusions can be drawn for Belgium:
- The inversion model of Infoterra-France (ITF) did not work very well in Belgium, in particular for maize. It tends to systematically over/underestimate for maize and sugar beet/potatoes. The main reasons identified are the geolocation problem of MERIS data at the time of analysis and the complexity of the landscape, characterised by small fields.
- Most promising results are obtained by the Neural Network (VITO) in Belgium. However, better results were in general obtained when using VGT instead of MODIS data. Further investigation should be made to clarify this surprising result, and to verify the performance of NN in less favourable conditions where less exhaustive in-situ data is available.

For the six districts of South West Rostov the following can be concluded:
- All methods work reasonably well for large fields, and
- There is no significant difference between the different methods.

Taking these points into account, the methods can be further improved and applied. Clearly it has to be considered in which regions the approach performs well and for which areas there are limitations. Therefore, further investigation should envisage, besides a longer time series of estimates, a range of test sites within varying landscapes and climates. For example extension of the methods to Africa is of particular interest as on the one hand the reliability of statistics on acreage in some African countries is questionable and on the other hand there a lot of uncertainty on area and spatial distribution of agricultural land. These information are however crucial for food security early warning systems and rural development policies. For those regions the models will still need to be tested and further research is required.

References:

Baatz, M. and Schäpe, A., 2000. Multiresolution segmentation: An optimization approach for high quality multiscale image segmentation. in J. Strbl, & T. Blaschke, (Editors), Angewandte Geographische Informationsverarbeitung. Heidelberg: Wichmann, pp. 12 - 23.

Fritz, S., Massart, M., Savin, I., Gallego, J. and Negre, T (submitted), The Use of MODIS data to derive acreage estimations for larger fields: a case study in the South-Western Rostov Region of Russia, International Journal of Earth Observation and Geoinformation

Lobell, D. B. and Asner, G.P., 2004. Cropland distributions from temporal unmixing of MODIS data. Remote Sensing of Environment 93, 412 - 422.

Stibig H-J., T. Bucha, 2005, Feasibility study on the use of medium resolution satellite data for the detection of forest cover change caused by clear cutting of coniferous forests in the northwest of Eurasia. Publication of the European Communities, EUR 21579 EN