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# The experience of application of NOAA AVHRR and Landsat-7 data for cereal crop yield forecasting

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ABSTRACT: Monitoring of vegetation changes at a regional level is one of master cells of the control and planning of usage of natural resources. The data from NOAA and Landsat-7 satellites are shown to be rather useful for carrying out such estimations. These data can be combined with meteorological information which is essential for an estimation of growth conditions of vegetation, namely precipitations, air temperature, solar radiation, relative humidity, wind speed, evaporation. One of the relevant outcomes of processing of these data is the fast and rather reliable forecast of productivity that is an extremely useful link for a decision making system of rural economics and planning of food safety. Therefore now a number of countries are making efforts to develop optimum monitoring of vegetation permitting simultaneously to conduct a reliable estimation of productivity.

These efforts are mainly based on the use of data of multiband NOAA AVHRR space images with the subsequent calculation of a vegetation index, first of all NDVI, its integration for the vegetation season and comparison with the archive data. The methods of regression analysis allow to establish relations between different combinations of NDVI values and meteorological data by the information with specific crop yield. As a result, the conforming charts and maps of the forecast, can be constructed, which are an output product of similar systems.

The purpose of the given activity is to formulate a similar system on an example of the Kiev region. Thus the methodical approaches developed are foreseen to be used for other regions both in the Ukraine and other countries.

A feature of a created system is that the attempt of maximum usage in regression data models of remote sensing and whenever possible minimally concomitant information will be made, which is not convenient for receiving from the open sources.

One of the problems of processing AVHRR NOAA data (resolution 1.1 km) is accurate comparison with ground truth information. The mode of this process influences on reliability of evaluation and it is one of the subjects of the investigation.

## 1 INTRODUCTION

The forecast of productivity of grain crops at a regional level - one of the major questions of agrarian science – on whose reliability depends the efficiency of policy on the state of the agriculture. The forecast has been carried out by different methods, mainly using data of ground researches that required significant expenses of forces, means and time.

In recent years in different countries NOAA/ AVHRR data have been widely used for regional forecasting of productivity, giving the best answer for this task. The systems of optimum monitoring of vegetation are developed for this purpose and give a reliable estimation of crop yield (Bochenek (2000), Bullok (1992) Illera *et al.* (2000), Rasmussen (1997,1998)). For example, since 1988 in EU countries the Programme on application of remote sensing for agriculture was initiated. This program is known as the MARS Project (Monitoring Agriculture by Remote Sensing). This Programme has developed methods of forecasting of a crop on the basis of computer decoding of space images with application of the software (CGMS - Crop Growth Monitoring System) for the control of a condition of crops and estimation of the future crop. This system was realized in 1996 and is based on agrometeorological models incorporating mainly meteorological and agronomic data, and also data on soil condition and is complemented by low-resolution space images from the NOAA satellites.

The methodology of use of NOAA images is being constantly improved by taking into account both regional features of the country in question and progress in the technology of images processing.

The purpose of our work is the creation of a similar system for the forecast of productivity of grain cultures, in particular, winter wheat within the limits of Ukraine. A feature of the created system will be the maximum use of remotely sensed data and minimally - accompanying information, which is difficult for receiving from open sources. Besides it should allow to work when there are not enough cloudless days, because of which the existing methods are not applicable. For the reception of authentic information about an opportunity of forecasting of grain cultures, as well as any other biological object, a three-year cycle of observation is necessary, as a minimum.

## 2 THEORETICAL PRECONDITIONS OF A METHOD

The theoretical basis of using NOAA/AVHRR data for the forecast of productivity is known dependencies of natural productivity of soil (NPP) from Absorbed Photosynthetically Active Radiation (APAR), which is accumulated for the growing season and is multiplied on a certain factor E, taking into account features of soils and climate of the given area.

So, agrees Kumar & Monteith (1981) the seasonal production of soils is:

So, agrees Kumar & Monteith (1981) the seasonal production of soils is:

$$P = E \int_{t}^{0} f_{par} \, PAR \, dt \, ; \qquad (1)$$

where $f_{par}$ – is the fraction of Photosynthetically Active Radiation (PAR),

P - seasonal production of soil in kg /ha,

0 and t - beginning and end of a growing season.

Agrees Ruimy et al. (1994), theoretically and experimentally analyzed connection between NDVI and APAR, $f_{par}$ can be replaced on NDVI, and then:

$$P = E \int_{0}^{t} (a \, NDVI + b) \, PAR \, dt \, ; \qquad (2)$$

Where a, b – coefficients of regression equation.

Taking into account, that E and PAR are in many respects constants for the certain area, the opportunity of an estimation NPP is shown, using only data NDVI [5]. Agrees Ruimy et al. (1994), factor E is determined by climatic conditions and, first of all, by water stress. Taking into account these preconditions, a number of researchers use NOAA/AVHRR data for the creation of empirical models of forecasting of crop yield, in particular, of grain cultures (Bochenek (2000), Illera *et al.* (2000), Rasmussen (1997,1998)). So the dependence between crop yield and accumulated sum of NDVI was established for the growing season with a factor of correlation about 0.7 (Illera *et al.* (2000), Rasmussen (1997,1998)).

Now the works conducted should increase the reliability of correlation of the satellite information and crop yield. For example, the attempts of the account of the meteorological factors - rainfall ($R_G$), temperature of air ($T_a$), temperature of ground ($T_s$) are done, of solar radiation ($T_{s^2}$) and the opportunities of use of the accumulated sums of NDVI (Σ NDVI) for certain periods for separate kinds of agricultural cultures and soils are analyzed. For the analysis of dependencies the methodology of multiple linear or nonlinear regression is used, and the results are represented as the concrete equations.

For example, such equation is received for the Castille area (Spain) by Illera *et al.* (2000). It successfully describes interrelation of crop yield of grain cultures with NDVI-MVC (maximum composite values of NDVI for 10-days) on AVHRR/NOAA images and agrometeotological data.

$$\text{Yield (kg /ha)} = \alpha + \beta NDVI_J + \gamma T_S^2 + \delta(T_S - T_a) + \varepsilon R\sigma \, ; \qquad 3)$$

where

$$NDVI_J = \frac{\sum_{1\,June-31\,July}\left(NDVI - NDVI_{January}\right)}{\text{num days}(1\,June - 31\,July)}; \qquad 4)$$

$$T_S^2 = \frac{\sum_{20\,April-10\,July} T_S^2}{\text{num days}(20\,April - 10\,July)}; \qquad 5)$$

$$R\sigma = \frac{\sum_{1\,May-10\,July} R_G}{\text{num days}(1\,May - 10\,July)}; \qquad 6)$$

$$\left(T_S - T_a\right) = \frac{\sum_{20\,April-10\,July}\left(T_S - T_a\right)}{\text{num days}(20\,April - 10\,July)}; \qquad 7)$$

means $\alpha = 8970$, $\beta = 3590$, $\gamma = -81$, $\delta = 2215$, $\varepsilon = 63$.

The parameters of temperature and rainfall in the equation emphasize the necessity of having information about water stress, as the water resources usually are the basic limiting factor in droughty regions. Using a similar equation, it is possible to receive a map of productivity for the whole research area.

A similar approach using the accumulated sum of NDVI for the forecast of millet on an example in Senegal is stated in the works of Rasmussen (1997, 1998), which makes an attempt to simplify as much as possible the forecast models, while still a high enough reliability of prediction. Some additional parameters, except for the accumulated sum of NDVI for the certain period of time, such as percentage of cultivated lands, can reliably enough be defined on the remote sensing data. The example can be served with the equations of the forecast of crop yield of millet for areas of Senegal, where the cultivated lands represent more than 22.5 %:

$$\text{Yield} = 774.1(\sum \text{NDVI}_{1\text{September}-10\text{Oktober}} - \sum \text{NDVI}_{1\text{May}-31\text{May}}) - 1195 ;$$

$$(r^2=0.729) . \quad (8)$$

In case percent of cultivated lands makes less than 22.5 %, there is a similar equation, but it is less reliable:

$$\text{Yield} = 3793.7(\sum \text{NDVI}_{1\text{September}-10\text{Oktober}} - \sum \text{NDVI}_{1\text{May}-31\text{May}}) - 254 ;$$

$$(r^2= 0.663). \quad (9)$$

However, if the percentage of cultivated lands (AGRIPRC) is known, then it is possible to establish by remote methods rather precisely and a more reliable model can be received:

$$\text{Yield} = 3881.1(\sum \text{NDVI}_{1\text{September}-10\text{Oktober}} - \sum \text{NDVI}_{1\text{May}-31\text{May}}) + 25.0\text{AGRIPRC} - 531$$

$$(r^2 = 0.763). \quad (10)$$

The advantage of such models is that there is no necessity to use significant volumes of ground data. In many cases such data are either difficult to collect, or they do not exist at all.

## 3 SATELLITE AND REFERENCE DATA

The results stated below of researches are a result of the first stage of works, whose purpose was to estimate the opportunities for the use of satellite images of low spatial resolution (about 1 km) for the forecast of crop yield of winter wheat on an example of the Kiev region. The estimation of crop yield is given at a level of administrative areas. The basic attention was given to accumulation of the initial data - satellite and ground information and their initial processing.

NOAA/AVHRR data are used in this work. Using this data, the NDVI index was calculated for its further integration for the growing season and comparison to the archival data on crop yield. In the first stage only for two years - 1996 and 1999 – were NOAA/AVHRR considered. These years were chosen because the crop yield of 1996 is close to average long-term, and in 1999 it was the lowest for the last 10 years. Besides the images for 2001 were received, given by the “Ukrainian Center of management of ground and resources”, (Kiev), for approbation of a technique for the second stage. As is known, in 2001 the highest grain crop for the last 10 years (39,8 million tons) was recorded.

In general, the system for an estimation of crop yield on the basis of NOAA/AVHRR data consists of the following stages:

- Organization of the NOAA/AVHRR collection during the growing season;
- Preparation of the special software for processing AVHRR/NOAA images;
- Creation of databases using GIS for realization of the spatial analysis;
- Preparation of the software for construction of models for the crop yield forecasting

The ERDAS Imagine 8.4 program was applied as the software allowing carrying out of geometric and radiometric correction of images and also for calculation of an NDVI index.

The AvcView and MapInfo were used for GIS operations.

Therefore the following data sets were generated:

1. All AVHRR/NOAA images with cloudless (clouds < 5%) for research area for the period April - September 1996 and 1999 and 2001.
2. Digital topographical maps of research area of scale 1:500 000, 1:200 000 and for some sites 1:25 000.
3. Statistical data on crop yield on 25 areas of the Kiev region in 1996 and 1999.
4. Agrometeorological data.
5. Soil map of Kiev region.

The information was transferred in digital formats for usein GIS systems MapInfo and Arc View.

## 4 PRELIMINARY RESULTS OF FORECASTING AND DISCUSSION

When processing images the following features, which are peculiar for the Kiev region, were noted – the quantity of images, where clouds is minimal, allowing to carry out measurements of NDVI indexes, was rather insignificant. For the growing season (4 months) there were 7 images in1996 and 8 images in 1999 year. Other images appeared unacceptable because of significant clouds. In this connection the techniques based on 10-day images of NDVI-MVC for the given region, are unacceptable.

The geometrical and radiometric correction of the assembled images of AVHRR/NOAA was carried out and the procedure of interrogation of spectral brightness of images for basic points with known co-ordinates is developed, that has then allowed to carry out comparison of the ground and satellite data.

The processing of the available data has enabled to establish dependence between the accumulated sum of NDVI (Σ NDVI) for the basic growing season, duration about 70 days (last decade of April - first decade of July) and the average crop yield of grains (Yield). These interrelations for 1996 and 1999 with reference to areas of the Kiev region are approximated by linear dependence (fig. 1).

For 1996 the equation is:

$$(\Sigma \text{ NDVI}) = 0.2631*(\text{Yield}) + 8.402 \quad (r^2=0.577).$$

The similar equation of regression for 1999 has a higher coefficient of determination:

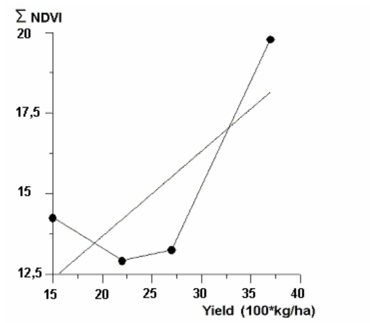
$$(\Sigma \text{ NDVI}) = 0.253355*(\text{Yield}) + 7.3146 \quad (r^2=0.734).$$

The analysis of dependencies specifies the necessity of a different approach to areas, which have an average crop yield more than 2 t/ha, separating them from those that have a crop yield of 1 - 2 t/ha. The areas with productivity less than 10 t/ha, as a rule, are badly entered in the given laws. Probably, it is connected that within the limits of these areas are clay loam and sand loam soils with low concentration of humus and having essentially other reflective characteristics. Hence, the search of laws of variability of crop yield is necessary for territories with homogeneous natural conditions that will be compared to conclusions of other authors.

Taking into account the lack of processing of NOAA/AVHRR images of a preliminary stage, on which the concrete sites of formation of crops of grain cultures were not defined, we began work with the purpose of better processing of images. First of all, such processing would allow (1) to determine pixels of NOAA/AVHRR images, which cover the areas of crops of grain cultures (first of all winter wheat), (2), to carry out forecasting of crop yield of grain cultures on the basis of the data of these pixels. Thus, the tasks both of distribution of the areas of grain crops cultures, and forecasting of crop yield at various phases of the growing season are solved.

As a basic polygon for the improvement of a technique of the decision of these tasks we used a southern part of the Kiev Oblast and, in particular, the Mironovsky region, where the numerous data of

a)




b)

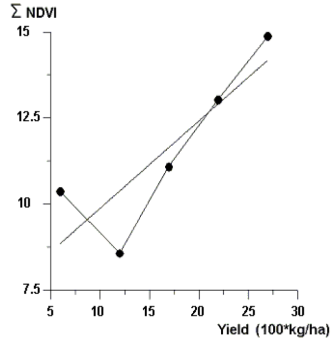



Figure 1. Dependencies of the average accumulated sum of normalised difference vegetation index (Σ NDVI) from crop yield: a) for 1996, b) for 1999.

field supervision are assembled. On the given territory besides a series of NOAA/AVHRR images for 2001, Landsat-7 images (18.05.2001) and (19.06.2001) also were ordered.

Using ERDAS Imagine 8.4 software and ground supervision on test sites, the classification of Landsat-7 images was carried out using Maximum Likelihood method. As a result of classification, the areas of crops of grain cultures, first of all, winter wheat and barley were established.

The verification of results of classification of Landsat–7 (May 18, 2001) on the basis of the test site has shown enough high reliability (more than 90 %), of accuracy of classification for winter wheat. Reliability of classification of the specified classes on the Landsat-7 image, which was made in June (19.06.2001), is a little bit lower. In some cases the summer grain cultures were wrongly referred to winter. But other crops - sugar beet, sunflower, corn are well allocated, which on a May image did not differ at all and were referred to one class – ploughed lands with rare vegetation.

Then the overlapping of classified Landsat-7 image (18.05.2002) with fragments of NOAA/AVHRR images was carried out. For example, the combination of classified Landsat-7 image (18.05.2002) with fragments of AVHRR/NOAA on 16.05.2001 is demonstrated on figures 2, 3. The analysis of this combination has shown a basic opportunity of detailed comparison of pixels of AVHRR/NOAA for different classes of vegetation and, first of all, of grain cultures with distribution of the areas of their crops. By such comparison the essential differences on spectral brightness of various classes of vegetation are observed. Ploughed lands with rare vegetation have low meanings of NDVI. The areas with winter wheat and long-term grass, are characterised by the highest meanings of this index and differ on the average by 0,4 unit in comparison with ploughed lands. The intermediate meanings of NDVI are characteristic for crops of summer barley and peas. These distinctions in the spectral characteristics of vegetation allow optimistically to estimate an opportunity of processing NOAA/AVHRR data with the purpose of carrying out the following tasks: 1) to estimate the areas with crops of a winter wheat, 2) to construct regression models, which should considerably increase quality and reliability of forecasting of crop yield at a regional level.

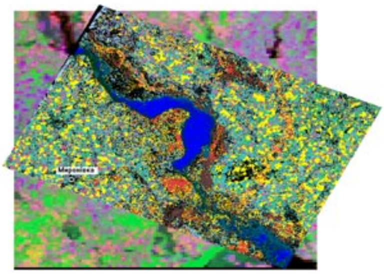


Figure 2. Overlapping of a fragment of the classified Landsat-7 image (18.05.2001) (revolved under a corner) with a fragment of NOAA/AVHRR image (16.05.2001г). Southern areas of the Kiev region. Yellow (light) sites on the Landsat TM image are areas of winter wheat


Figure 3. The increased fragment of the classified Landsat-7 image (18.05.2001) with a fragment of the NOAA/AVHRR image (16.05.2001г). Area of detail polygon researches (Mironovsky region of Kiev Oblast)

## 5 CONCLUSIONS

1. The use satellite data of NOAA/AVHRR allows to receive fast and reliable yield forecasts of grain crops, that are necessary for decisions making in the field of planning of food safety. Now in a number of countries, work is conducted to improve the system for the optimum monitoring of vegetation, that will allow simultaneously to carry out a reliable estimation of crop yield.

2. The systems of crop yield forecasting, according to the literarature, are mainly based on the use of NOAA//VHRR data and the definition of an NDVI index with its subsequent accumulation for the growing season and comparison to the archived data on crop yield and agrometeorological information.

3. The work carried out has shown that the system of an estimation of crop yield based on a 10-day period of NDVI-MVC in conditions of the Kiev region are not applicable because of the limited quantity of cloudless days.

4. The dependence between the accumulated sum of the NDVI for the basic period of vegetation (April - July) and the average crop yield of winter wheat is established. The character of this dependence is different in areas with crop yields of less than 1 t/ha, 1-2 t/ha and more than 2 t/ha. It is shown that this is connected with the differences of natural conditions in these areas.

5. The analysis of a combination of Landsat and NOAA/AVHRR data for 2001 testifies to an opportunity of application of NOAA images, both for an establishment of the areas with winter wheat, and for the construction of regression models, that should considerably increase the quality and reliability of the crop yield forecasts of grain crops at a regional level.

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