Studying the growth rate of plants according to the values of the vegetation index

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Abstract. The article discusses a method for assessing the growth rate of plants, as a variant of understanding the ripening time and understanding the harvesting time of an agricultural crop. In most well-known software products, as a rule, they operate with averaged data on the field area, which is a very rough approximation, since fields can have different topography, water supply, soil types, etc., which affects the growth rate of plants. This article presents an approach to assessing the growth rate of an agricultural crop based on the dynamics of the NDVI vegetation index for each pixel of a satellite image. Multispectral images of the MSI Sentinel-2 device are taken as satellite data. The results of the assessment of the vegetation index and growth rate of agricultural crops, as well as the values of temperature, humidity and total precipitation for four months (May, June, July and August) are shown. The proposed results can be used in various farms to estimate the time of ripening and, accordingly, the harvesting of crops.
Keywords: Sentinel-2 multispectral instrument, NDVI vegetation index, winter wheat, growth rate estimation.

1 Introduction

In the context of significant climate change, there is a need to develop not only methods for monitoring agricultural areas, but also to develop appropriate mathematical approaches for processing and analysis. One of the most efficient and informative monitoring options is the use of multispectral remote imaging of the Earth's surface from space [1]. Preliminary and thematic processing of a large amount of remote data, as well as analysis of the results obtained, requires modern approaches that allow not only obtaining scientific, but also practical results. One of these approaches is based on the study of the spectral characteristics of the soil and vegetation cover of the surface of agricultural fields, obtained from space multispectral images, in order to carry out various kinds of calculations leading to the calculation of vegetation indices.

Timely spatial and temporal detection of vegetation in different states allows assessing the possible risks of applying certain agronomic approaches and, accordingly, developing the right decision in agricultural management [2]. The identified problematic aspects of vegetation growth stages include: identification of areas of weak seedlings, death of crops, drying out or vice versa, waterlogging of agricultural lands, an increase in weed habitats,

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etc. The use of special indices obtained on the basis of satellite data for each point in the space of the field contributes to the development of technology for interpreting satellite images and obtaining quantitative characteristics of plant dynamics.

To obtain images from satellites, various survey equipment is used, which registers solar radiation reflected from the earth's surface in the visible region of the spectrum. The processing of such information makes it possible to obtain up-to-date and accurate information about the area, relief, soil specifics of fields, plant growth processes, as well as plant productivity, biomass and intensity of photosynthesis. Observations of the dynamics of the development of agricultural crops according to space images have shown their reliability and accuracy for a long time.

The purpose of this work is related to the development of software that allows obtaining cloudless (no more than 15% of cloudiness in the image), pre-processing (atmospheric correction), performing NDVI calculation and estimating plant growth rate. To understand the growth rate of plants, meteorological data are obtained in parallel with satellite data.

2 Materials and methods

Vegetation index.

A quantitative characteristic of the state of crops is the normalized vegetative index NDVI, defined as the ratio of the difference between the intensities of reflected light in the near infrared and red ranges of the spectrum to their sum. In the red region of the spectrum, there is a maximum absorption of solar radiation by chlorophyll, and the near infrared region is responsible for the maximum reflection by the cellular structures of the leaf [3]. When shoots appear, during the growing season, the growth of the crop corresponds to an increase in NDVI values, and with the onset of the ripening period, the chlorophyll content and, accordingly, the NDVI values decrease. A decrease in NDVI values during the period of active vegetation indicates the state of plantings of vegetation, since during this period of time plantings may be affected by diseases or pests, the presence of weed areas, and the result of natural phenomena (hail, rainstorms, drought, fires). Currently, several hundred different variants of vegetation indices are known, which are used for various objects (water, soil, plants) [4]. The indices are selected on the basis of the known features of the behavior of the curves of the spectral reflectivity of vegetation and soil [5].

NDVI as an indicator of plant growth dynamics.

Analysis of the dynamics of the vegetation index is widely used in solving specific problems of agriculture and forestry. The NDVI indicator used to monitor the condition and productivity of crops is currently the main parameter that is obtained in the course of remote sensing of the Earth. Among the advantages of using the NDVI index, one can note, first of all, the possibility of promptly obtaining reliable data on vast territories. Also important from a practical point of view is the possibility of obtaining data in hard-to-reach areas and, of course, the strict frequency of re-surveying the same area at the required time intervals [4].

The disadvantages of using the NDVI index are: insufficient information content of the values, which is associated with the dependence of data on the relief and conditions for obtaining satellite data, a strong dependence of the brightness in the studied spectral ranges on the parameters of the environment (the presence of an interfering factor of cloudiness and transparency of the atmosphere, the angle of incidence of light, type of soil, etc.). We also note that recently much attention has been paid to the development of a software component that allows processing and visualizing satellite information, and in particular data representing the values of vegetation indices.

However, in such works, various approaches are used, which do not allow one to obtain comparative characteristics of the results of assessing the state of vegetation based on satellite measurements. Many authors determine deterioration or improvement in vegetation by comparing NDVI values for two or more years of surveying. Approaches for comparing these quantities can be either visual or statistical. To assess the rate of change in the vegetation index, an index was proposed that takes into account not individual NDVI values, but the change in these values during the growing season - the Vegetation Condition Index (VCI). VCI is expressed as follows:

$$VCIj=(NDVIj - NDVImin)/(NDVImax-NDVImin)*100\% \quad (1)$$

Where VCIj is the value of the vegetation growth conditions index for date j; NDVIj – image of NDVI values for date j; NDVImax - display of the maximum NDVI values within the entire dataset; NDVImin - display of the minimum NDVI values within the entire data set. In fact, VCIj is the percentage of NDVI values for time j in relation to the maximum amplitude of changes in NDVI values for the considered period of time.

VCI is used as an indicator of vegetation growth conditions in a given region. This index allows you to evaluate relative changes in the index, but not the rate of change, which we propose to look for by the expression:

$$S(x,y,t)=(NDVI(x,y,(t+1)) - NDVI(x,y,t))/((t+1)-t) \quad (2)$$

Here (x,y) is the image pixel, t is the time of acquisition of satellite images.

The relationship between the vegetation index NDVI and growth characteristics, as shown by many studies, is not direct and unambiguous. Repeated attempts to establish a regression relationship between the vegetation index and yield have not yet led to a completely unambiguous result. It is clear that there is some correlation between the vegetation index values and meteorological parameters and soil quality, but the interpretation of such a relationship cannot be considered generally accepted. We assume that there is a close information relationship between the vegetation index and temperature and humidity, which was found in the course of studying the forms of change in NDVI values.

3 Results and Discussion

The initial data at our disposal were image arrays of multispectral images of the MSI Sentinel-2 satellite instrument for four months (May, June, July and August) from 2017 to 2021. After receiving images, they are pre-processed using the well-known Sen2Cor procedure, which we modified by entering not tabular meteorological values, but current values obtained from Roshydromet resources. Next, the NDVI values of winter wheat crops were calculated for fields located near the city of Tomsk (Figure 1). Note that the field is difficult for cultivation and plant growth, as it has a rather complex relief, as can be seen from the image, where water flows are clearly visible. The obtained results of the vegetation index and the rate of change of the index are shown in Figures 2 and 3, these data were acquired with a resolution of 10 m, which is good enough for agricultural applications. The quality of the results obtained lies in the fact that on the pixel area, in most of the area, homogeneous surface areas are located. To understand the results obtained, in Figures 2 and 3 we present tabular average monthly values of temperature (Figures 4) and humidity (Table 1) and precipitation volume (Table-2).

Fig. 1. Image of the analyzed agricultural field near the city of Tomsk (image obtained using the Google Earth program).

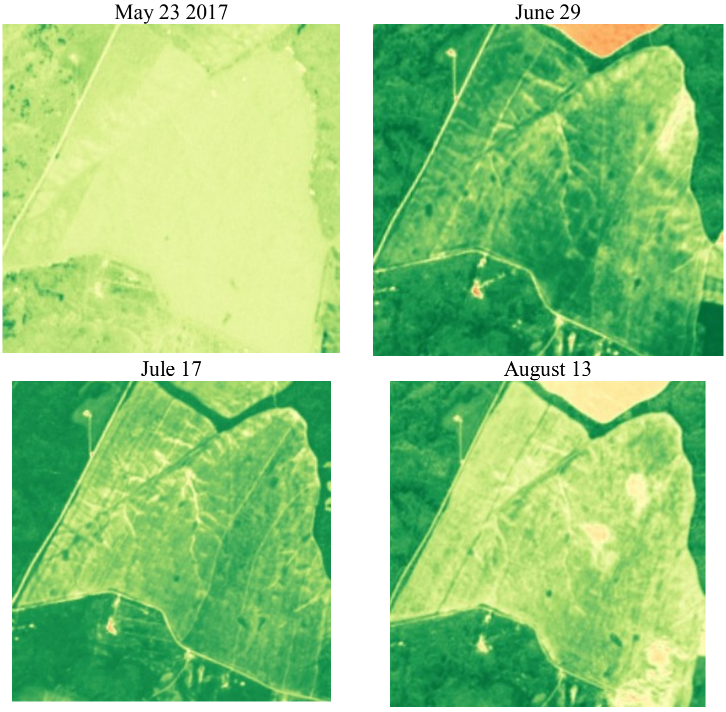

Fig. 2. Spatial changes in the vegetation index in 2017.

Figure 2 shows the values of the vegetation index in the main months of growth of winter wheat in the conditions of risky farming in the Tomsk region. It can be seen from the figure that in May the values of the vegetation index are small and increase in June and July, and in August it begins to decrease again. Figure 3 shows the spatial changes in the vegetation index in 2021, which differ from the values of the vegetation index in 2017.

From Figures 2 and 3 you can see some spatial features of the development of plants in the field, but it is difficult to say how the plant grew, which was the motivation for us to calculate the growth rate of vegetation, which is presented in figure 4 for 2017 and Figure 5 for 2021. From these figures it can be seen that the growth rate of plants is well consistent with the growing cycle, where there is a small plant growth at first (May), accelerated growth (June), maturation (July) and final ripening (August).

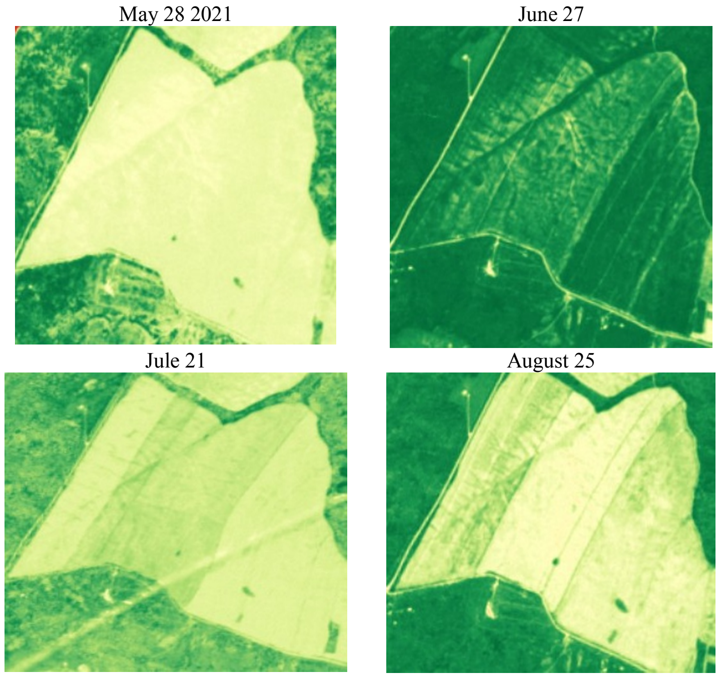

Fig. 3. Spatial changes in the vegetation index in 2021.

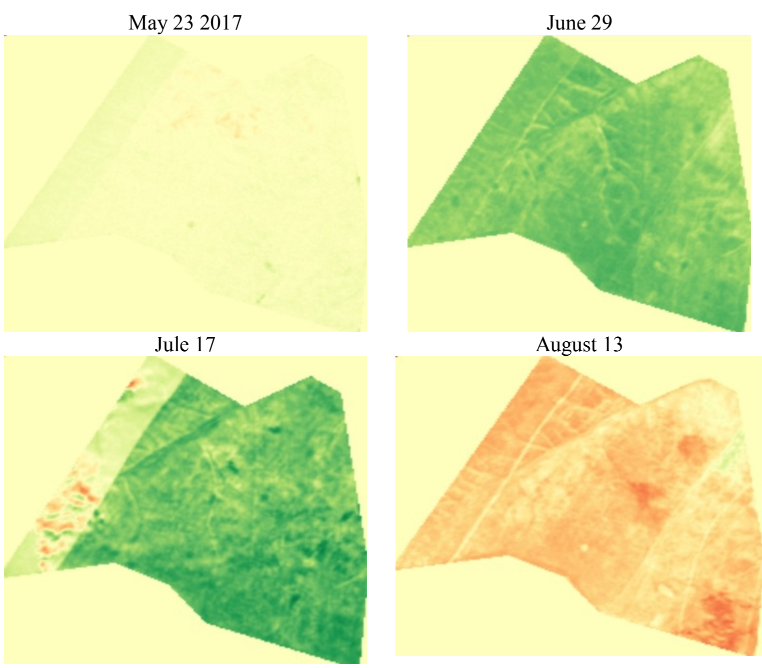

Fig. 4. Spatial values of plant growth rate in 2017.

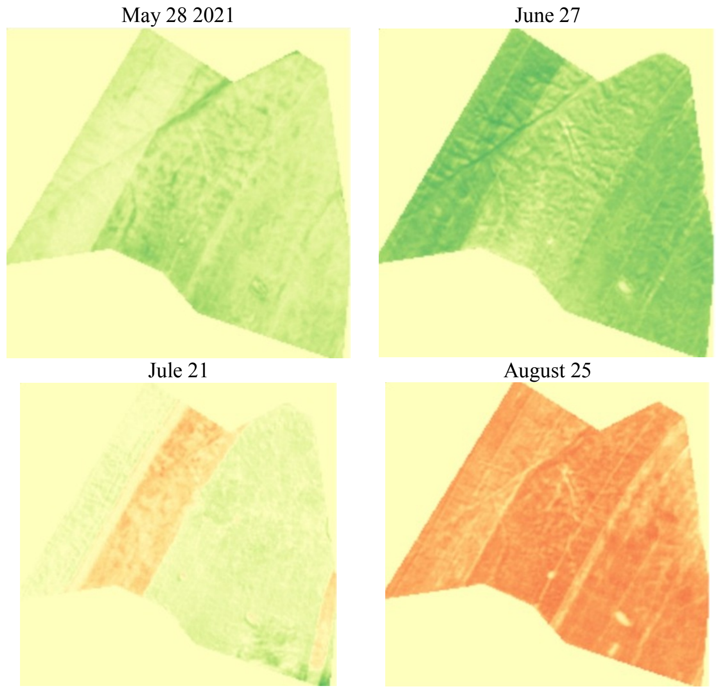

Fig. 5. Spatial values of plant growth rate in 2021.

To observe individual pixels of images of spatial changes in the vegetation index, one can observe the time course, which is shown in Figure 6.

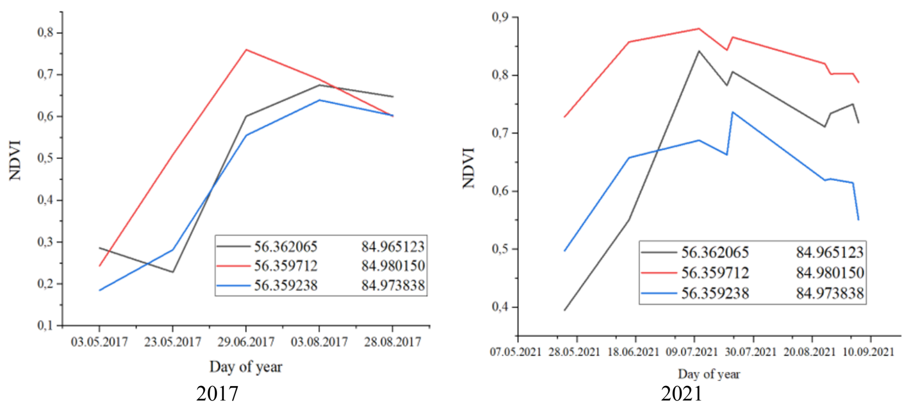

Fig. 6. Spatial values of plant growth rate in 2021.

It can be seen from Figure 7 that in 2021 the air was warmer than in 2017, which led to earlier ripening of winter wheat. To confirm this conclusion, we obtained the values of humidity (Table 1) and the amount of precipitation for the month (Table 2) [6].

Tables 1 and 2 show that in July, the humidity in the month of plant ripening in the agricultural field was higher in 2021, as was the amount of precipitation. These results confirm the earlier ripening of winter wheat in 2021 compared to 2017.

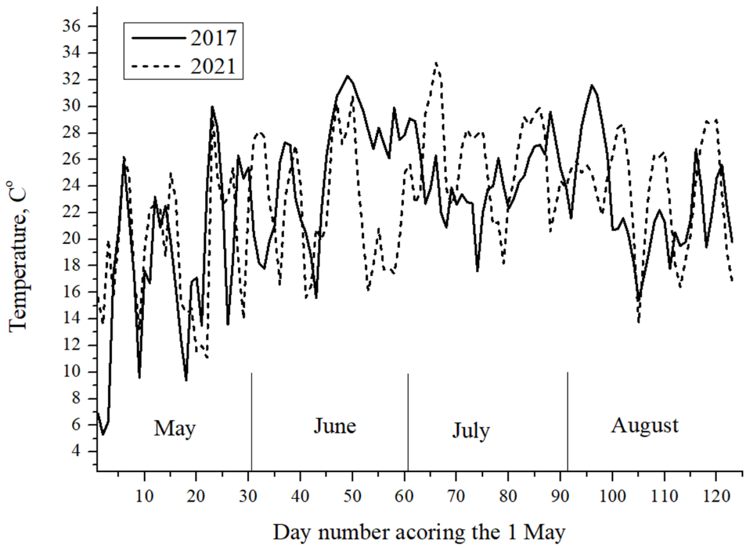

Fig. 7. Daily temperature changes in the region of Tomsk for 2017 and 2021, for the months of satellite image measurements.

Table 1. Values of Partial pressure of water vapor (mm Hg).

Year	May	June	July	August
2017	3.0	5.1	7.1	13.7
2021	3.5	5.2	10.2	11.4

Table 2. Monthly precipitation values (mm).

Year	May	June	July	August
2017	80.8	67.7	23.5	114.8
2021	48.2	26.4	95.2	94.0

4 Conclusion

The paper presents the results that show the need to calculate not only the vegetation index, but also the rate of change in plant growth, together with meteorological parameters. For these purposes, the authors have developed an appropriate software package, the data base for which are multispectral images of the MSI Sentinel-2 device. This program complements the complex of programs developed by the authors and described in the articles [7-8]. Over time, new satellite remote sensing devices appear and the images they produce require the development of separate software applications that expand the possibilities of scientific and practical applications of satellite data.

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