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A study of backscattered spectra dynamics of agricultural crops during growth period on the territory of the Krasnoyarskii Krai (Russia)

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Abstract

The work presents the results of the study aimed at determining the seasonal dynamics of the spectral brightness and reflectance of agricultural crops (wheat, barley and oats) in the Krasnoyarskii Krai (Russia). The analysis of spectral curves obtained through field ground measurements and from satellite data showed that fine spectral differences can be used to study the spatial distribution of various types of vegetation and their ecological state. Based on the created electronic spectral brightness data base, the possibilities are shown of using spectrophotometric information for determining morphophysiological changes occurring in the plants and their species composition. The determined contrasts can be effectively used to obtain necessary information while processing space images, which suffer from natural interferences (varying optical thickness of the atmosphere, cloudiness, alterations in the scanner's angle of view, varying solar height, and highly inhomogeneous underlying surface).

Keywords: Spectral brightness coefficients; Spectral reflectance; Wheat; Barley; Oats

1. Introduction

The primary objective of satellite and aerospace monitoring of agricultural crops is to discern the croplands and determine the species composition of the crops and morphophysiological changes occurring in them. Identification of plants in satellite images may be difficult because plants change significantly as they grow (Kondratiev and Fedchenko, 1982; Kochubei et al., 1990; Rachkulik and Sitnikova, 1981; Krinov, 1947). The necessary amount of the relevant information can only be obtained from remote sensing data.

Although there are very many different varieties and species of agricultural crops, they all have similar brightness, reflectance, and absorption spectra. This is largely accounted for by the absorption capacity of chlorophyll, carotenoids, and other pigments in the PAR range (photosynthetically active radiation, $\lambda = 380–750$ nm) as they actually determine the form and dynamics of spectral brightness of plants (Kondratiev and Fedchenko, 1982; Kochubei et al., 1990; Terskov et al., 1983; Sidko et al., 1985; Sidko and Shevyrnogov, 1997, 1998; Sidko, 2004; Shevyrnogov and Sid'ko, 1995, 1998).

Contemporary geo-information systems of gathering and processing space images of land vegetation covers use spectral portraits of ground-truth measurements, ignoring their seasonal variations and the state of the plants. Owing to the availability of portable spectrophotometers and the updates of the databank of the MODIS/Terra satellite (performed on a daily basis since 1999), spectrophotometric information can be used to evaluate physiological and biological parameters of agricultural crops throughout their growth period.

In spite of certain achievements in using remote sensing methods to evaluate the state of agricultural crops, their

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development is hindered by the lack of comprehensive experimental field data that would cover the whole growth period.

In this paper we present the results studying of ground-truth and satellite measurements of reflectance from agricultural crops during their active growth period. The main purposes are receiving spatial-temporal variability of physiological and biological parameters and determining the species composition of agricultural crops by using reflectance dynamics. All observations was conducted on the territory of the Krasnoyarskii Krai (Russia).

2. Methods and material

Physiology and biology of agricultural crops are well-studied. Agricultural crops are convenient model objects for studying their spectral brightness and reflectance by remote sensing techniques.

2.1. Ground-truth studies

Dynamics of spectral brightness coefficients (SBC) of agricultural crops and morphophysiological parameters of such crops as wheat, barley, and oats were studied regularly for 15 years (Sidko et al., 1982, 1985; Terskov et al., 1983; Sidko et al., 1985; Sidko and Shevyrnogov, 1997, 1998; Sidko, 2004; Shevyrnogov and Sid'ko, 1995, 1998). Model crops were the wheat (*Triticum acstivum* L.) cultivars Skala, Ravnina, Bogarnaya, and Irtyshanka; the barley (*Hordeum disticxon* L.) cultivar Viner, and the oat (*Owena sativa* L.) cultivar Mutant and Oryol.

Brightness spectra of the crops were taken from germination to maturity, using a dual-beam field spectrophotometer designed at the Institute of Biophysics Siberian Branch of Russian Academy of Sciences. Measurements were taken from 10 to 17 h; the spectrophotometer was installed on a mobile elevating work platform at heights 2–18 m, usually towards the nadir. The angle of view was varied from 1° to 10°. The daily trend in plant SBC variations remained practically the same. Spectra were measured within the spectral range from 400 nm to 850 nm, with spectral resolution ±2 nm (Sidko et al., 1982, 1976). Etalon (MgO) with 98% reflection in visible spectrum was used in all measurements. SBC (ρ_λ) of crops were calculated under observation at nadir:

$$\rho_\lambda = \frac{B_\lambda}{B_\lambda^0}, \quad (1)$$

where B_λ – SBC of crops, B_λ^0 – SBC of etalon.

The spectra of crop SBC were taken every 2–4 days. Taking into account crop heterogeneity and aiming at determining the SBC distribution over the study field as accurately as possible, we took 20–30 spectra, which were subsequently averaged; the deviation in determining ρ_λ for one array was not higher than $1 \pm 1.5\%$ (Terskov et al., 1983; Sidko et al., 1985; 2008; Sidko and Shevyrnogov, 1997, 1998, 2000; Sidko, 2004; Shevyrnogov and Sid'ko, 1995, 1998).

2.2. Satellite data

The dynamics of spectral reflectance of wheat, oat, and barley crops over their growth period was studied based on satellite information from MODIS/Terra (a MOD09GHK product): the data of the visible bands (459–479 nm (Band 3), 545–565 nm (Band 4), 620–670 nm (Band 1)) and the near infrared band (841–876 nm (Band 2)), at 500 m spatial resolution (http://modis.gsfc.nasa.gov/). Study sites were croplands situated in the Balakhtinskii District in the Krasnoyarskii Krai. The areas of these sites are 490 ha (wheat fields), 325 ha (oat fields), and 250 ha (barley fields), and they can be discerned in 500 m resolution images. Coordinates of the fields in space were determined using 1:25 000 scale skeleton maps of the position of the fields and the data of Google Earth (http://earth.google.com/). Satellite data are available by using the Warehouse Inventory Search Tool. Preprocessing of MODIS/Terra data was conducted. Data with Sun Zenith more 60°, Zenith of view more 40°, data with cloud and cloud shadow were excluded from analysis. Data provider carried out atmospheric correction of MOD09GHK data. And data processing was conducted using the ENVI 4.0 software.

The obtained ground-truth and satellite data were exported to Microsoft Excel for statistical processing and data visualization through constructing 3D graphs. Statistical processing was done to calculate the following parameters: the mean value of the reflection of the study area, the confidence interval for the mean with the statistical significance (p-level) equal to 0.05.

3. Results and discussion

Our previous studies (Sidko and Shevyrnogov, 1997; Shevyrnogov and Sid'ko, 1998, 2008; Sid'ko and Shevyrnogov, 2000; Sidko, 2004; Terskov et al.,1983) proved that variations in the SBC (ρ_λ) of agricultural crops during their growth period are very informative. Analysis of the field data for the whole growth period showed that the 550–740 nm spectral range varied to a greater extent than other regions of the spectrum and that these variations were closely related to chlorophyll "a" content of the studied crops (chlorophyll "a" absorption region of the red band $\lambda_{max} = 680$ nm) (Fig. 1). This is essentially the result of the active processes of chlorophyll accumulation and decomposition in plants, which may serve as an indicator of the changes occurring in them (Sidko et al., 1982; Shevyrnogov and Sid'ko, 1995; 1998; Sid'ko and Shevyrnogov, 2000).

Of particular significance are variations in SBC in the chlorophyll "a" absorption region of the red band, which can provide a clue for decoding satellite spectral images. Variations in chlorophyll content of phytoelements are clearly reflected in the SBC curves of the studied crops in the phytopigment absorption region of the red band. Vari-