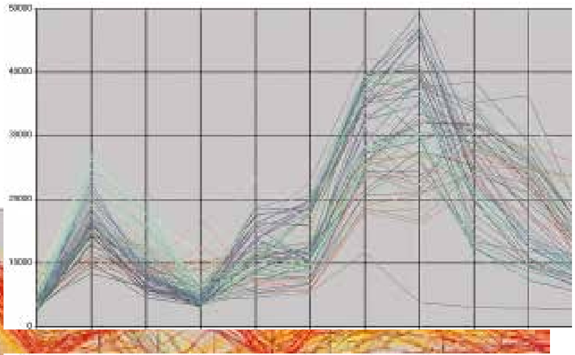
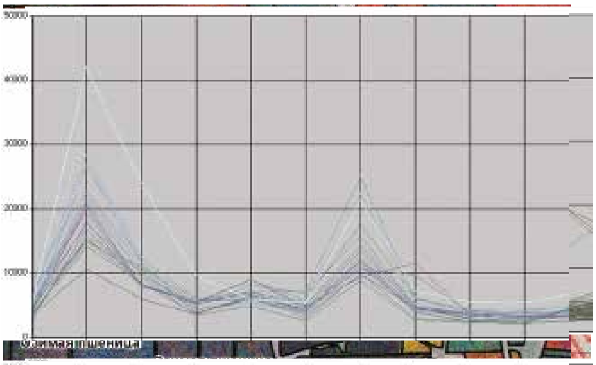
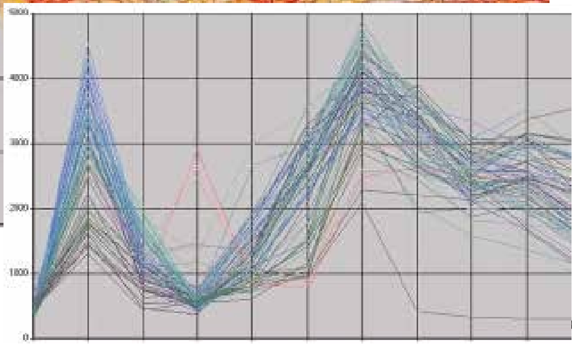
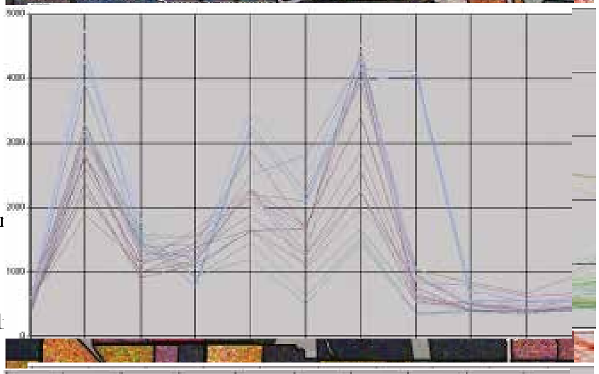
We live in an era of open and accessible

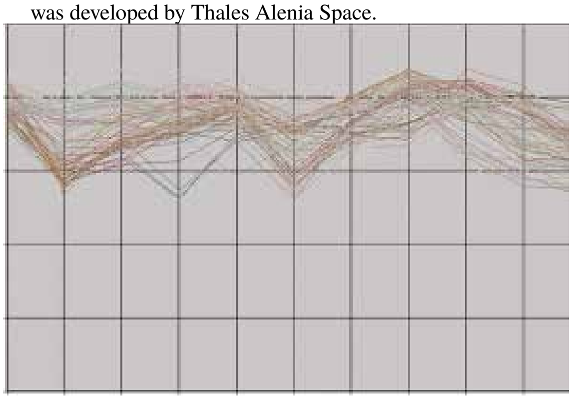


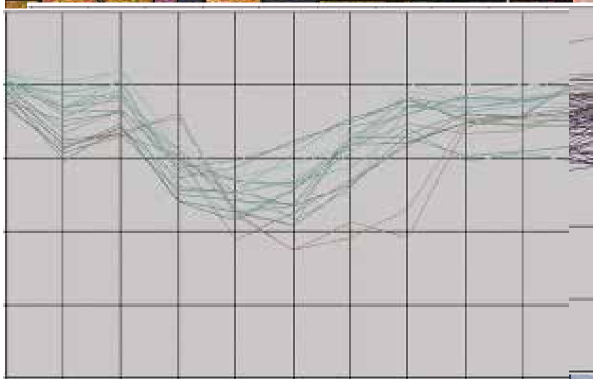






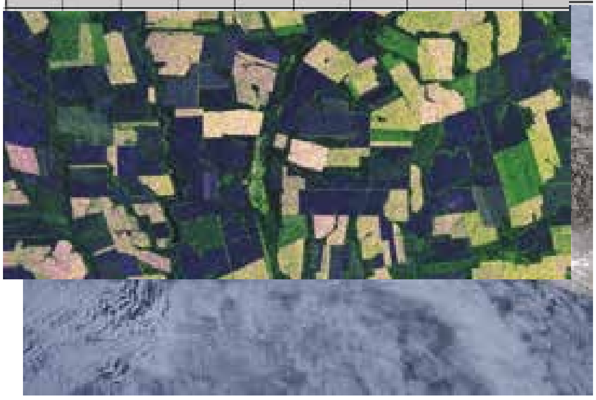
was developed by Thales Alenia Space.





of shooting modes are shown in the table. 1 [1].

Periodicity
gettings
snapshots
from the Sentinel-1A satellite for Russian
latitudes is 5-15 days.



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In 2004, he graduated from the Belarusian State University with a degree in Geography. He worked at the research enterprise for land management, geodesy and cartography "BelNITsem" (Minsk, Belarus). Currently, he is the head of the Department of thematic processing of remote sensing data at Sovzond.

Radar capabilities Sentinel-1 images for solving agricultural problems

Figure 1. General view of the Sentinel-1A satellite

The development of a survey system with such characteristics challenges the scientific community — what new tasks will be solved on the basis of free regularly received radar images? Taking into account the growing scientific and practical interest in the implementation of infocommunication technologies in agriculture, the proposed study aimed to understand how freely distributed regular data from Sentinel-1 satellites can be used to solve agricultural problems. Four tasks of potential use of Sentinel-1 data were identified a priori:

- development and testing of a general methodology for processing remote sensing radar data Sentinel-1 for agricultural purposes;
- mapping the composition of sown crops crop rotation control;
- monitoring the state of vegetation;
- monitoring the progress of agricultural technology projects works'.

Based on the general theory of radar, it is known that image formation is based on the reflection and scattering features of the emitted radar signal by various surface types [2]. In relation to agricultural tasks, the role of the surface is played by crops and open plowed soil. The total total reflection intensity of the signal (pixel brightness) is affected by the biophysical characteristics of vegetation, such as such as the density of crops, the height of stems, and the location of leaves. Since the survey is conducted with a significant angle of deviation from the nadir, even such a factor as the direction of plowing and sowing is important. Thus, the intensity of signal reflection in two fields sown with a crop of the same variety in the same vegetation phase, but plowed and sown at different angles, will differ (Fig. 2). The moisture factor of the soil and vegetation cover, which determines its dielectric permittivity, is of great importance [3].

The advantages of radar imaging for solving agricultural problems include::

- independence from weather conditions;
- independence from light conditions;
- sensitivity to biophysical factors

Figure 2. *Radar signal reflection by different parts of plants and soil [4]*

Table 1. *Characteristics of the Sentinel-1A satellite survey modes*

Strip Map Mode	80	5x5	VV+VH or HH+HV
Interferometric Wide Swath	250	5x20	VV+VH or HH+HV
Extra-Wide Swath Mode	400	20x40	VV+VH or HH+HV
Wave-Mode	20x20	5x5	VV or HH

(humidity, biomass) and structural and geometric features of the soil and vegetation cover.

The disadvantages of radar images are:

- complexity of thematic interpretation.
- data noise level.
- influence of terrain and slope angle.
- negative impact of roughness surfaces.

Immediately prior to the launch of the Sentinel-1 mission, the European Space Agency jointly with MDA (Canada) - a leader in the field of remote sensing technologies - a study was conducted to assess the possibilities of using Sentinel-1 images for agricultural purposes [5].

In the course
of the conducted studies
, the possibilities of various polarimetric
survey modes were evaluated, a methodology
for processing remote sensing radar data
in the C-band for
land use mapping and monitoring
agricultural growth parameters
was developed, and the optimal
viewing angle for monitoring crops
and crops was determined.

optimal settings
parameters
orbits
(ascending or descending),
reference
crop signatures are collected and analyzed.

The results of joint ESA and MDA studies led to the following main conclusions::

- It is possible to classify agricultural crops based only on data with double polarization.
- Crop classification accuracy of more than 70% is achieved when using five different-time images, and more than 80% is achieved when using seven different-time images.
- Double polarization VV+VH allows you to get more accurate results than double polarization HH+HV.
- Best classification results crops are reached based on summer images (more than 80% by August).
-

Full polarization can be useful for detecting stem crops (cereals, corn).

- The correlation with NDVI measured from RapidEye images and field measurements is highest in rapeseed and legumes.
- VH polarization to some extent fits for simulations NDVI in the early stages of vegetation.

The ESA and MDA study was conducted for test sites located in Canada, the Netherlands, and Spain. Since 2015, the south of the European part of Russia has been included in the Sentinel-1 plan for regular Interferometric Wide Swath surveys. The main characteristics of the resulting images are as follows:

- spatial resolution of 20x5 m (in the longitudinal and azimuthal directions);
- shooting angle 29-46 deg.
- double polarization — VH and VV.
-

capture band 250 km.

- the frequency of shooting is 5-12 days (depending on whether the loop overlaps or not).

Studies of the possibilities of Sentinel-1 radar images for agriculture in relation to the conditions of Russia were conducted for the territory of the Novonikolaevsky district of the Volgograd region, and more precisely , for the territory of the fields of Helio-Pax LLC.

Images of the GRD processing level were used as source data. This means that a significant part of the pre-processing procedures, such as projecting from the plane of the inclined range to the plane of the earth's surface, for images has already been carried out by the operator [6]. The observation period is from March to November 2015. Crop rotation data for 2015 was kindly provided by Helio-Pax LLC.

The open source software SNAP, developed by the European Space Agency, was used to process the radar images . SNAP includes a Sentinel-Toolbox panel specifically designed for processing data from Sentinel satellites. It should be noted that the Sentinel-Toolbox geoprocessing algorithms are available for use through the open GetHub libraries, and therefore can be easily integrated into third-party applications of developers around the world.

All images for 2015 were downloaded from the ESA portal to the study area In total, from March to November , scenes corresponding to 18 observation dates were obtained (the entire territory of the district). and 36 dates (eastern part), which indicates an unprecedented frequency of data collection. In other words, with a few exceptions, new images were uploaded at intervals of 1 every 12 days. Next , everything downloaded data scenes they were subjected to various pre -processing operations. The general scheme of performing preprocessing is shown in Fig. 3. At the output , calibrated scaled mosaics were obtained, ready for signal intensity measurements . For clarity and convenience of visual perception, pseudo-color RGB composites were formed, where

the red channel corresponds
to the image in the VV polarization,the green
channel corresponds to the image in the VH polarization,
and the blue channel corresponds to the quotient of
the images in the VV and VH polarization
(Fig. 4).

To solve the problem
of crop classification and mapping
crop rotations, it is necessary to study
the nature of crop rotation.
intensities
scattering
of the radar signal. This operation

Figure 4. Sample of the processed Sentinel-1 snapshot. Date of shooting 20.07.2015. Composite RGB image: R is the signal intensity in the polarization VV; G is the signal intensity in the polarization VH; B is the quotient of dividing the intensity in the polarization VV by the intensity in the polarization VH.

Uploading data to the area of interest
Correction of terrain impact
Radiometric calibration
Crop by area of interest
Creating mosaics
Speckle filtering of images
Calculating indexes
Building composite images
Coordinate-projection transformations

Figure 3. Sentinel-1 Snapshot Preprocessing Steps

It is similar to the study
of spectral reflectivity.
abilities
objects
when
processing optoelectronic images. To
perform the operation on
a given territory, a set of training samples
(signatures)was embedded based on available data
on crop rotations. Statistical indicators were calculated for each sample that
completely falls within the limits of a separate
field
. In Fig. 5 shows the results
of statistical analysis in the form of curves
displaying
change
the nature
of scattering of the radar signal on
time-varying images.

As can be seen from Fig. 5, the mutual separation of signatures of the main crop classes leaves much to be desired. In contrast to optoelectronic images , it is noteworthy that there is no sequential course of vegetation schedules corresponding to certain phases. First of all, this suggests that the nature of signal scattering is influenced by other factors, not always due to the biophysical parameters of vegetation. The analysis of meteorological observations at the nearest weather stations on the dates corresponding to the dates of the obtained images showed that one of the main factors affecting the intensity of signal scattering in Sentinel-1 images is the surface humidity factor. Peak dispersion values characteristic of certain observation dates correspond to the days on which precipitation was recorded,or immediately after the days with precipitation.

In addition to analyzing the scattering of the radar

signal in two polarization modes
, the study
attempted to derive a normalized index
based on the spatial relationship
of the polarization modes.
Normalized
indexes, so-called "radar NDVI", were calculated for each date
.

The calculation of "radar NDVI"
makes it possible to compensate for the influence
of the humidification factor to a certain extent. The radar
NDVI graphs also showed a good separation
of winter and spring crops
in the early stages (May), which is clearly
seen in Fig. 6. Row crops
(sunflower and corn).

Figure 5. *Character of radar signal scattering by different types of agricultural crops. X-axis — survey dates, Y - axis-scaled*

scattering intensity of the radar signal: a) time series of signal intensity in polarization VV; b)time series of signal intensity in polarization VH

but
b

they separate in the second half of summer and early autumn, when there is an active increase in biomass and they are characterized by large size of stems and leaves.

In Fig. 7 shows multi-time composites in various polarization modes. The figure shows the potential for remote recognition of various agricultural crops based on information about the scattering radarnogo the signal, received from the Sentinel-1 satellites.

One of the key tasks solved with the help of remote sensing data in the interests of agriculture is monitoring and evaluating the state of crops. Vegetation and soil parameters potentially available for observation by radar images include [2]:

•

type of culture.

- phenological phase of the culture;
- moisture content in plant tissues;
- the volume of biomass;
- projective cover.
- height of stems.
- diameter of stems.
- direction and density of plowing.
- soil moisture;
- surface roughness.
- structure of the soil cover.

Let's consider the features of radar signal scattering by individual types

Figure 6. *The nature of the time course of the"radar NDVI" for various agricultural crops.*
X-axis – dates of shooting, Y - axis- values of "radar NDVI"

Figure 7. *Mapping of agricultural fields on Sentinel-1 multi-time composites:*
R – Date of shooting 29.07.2015;
G – Date of shooting 23.06.2015;
B – Date of shooting 30.05.2015.
a) Images in the VV polarization;
b) Images in the VH polarization

but

b

agricultural crops on the example of winter and spring wheat, barley, corn and sunflower.

Figure 8 shows the scatter plots of the radar signal for winter wheat. Several sharp jumps in the scattering intensity are noteworthy , which are especially clearly shown in the images in the VH polarization. As noted above, the cause of abnormally high values and intensity is the moisture content of vegetation cover and soil. Dates that have peak values (May 6, June 23, and July 17) are characterized by increased surface moisture, which follows from the readings of meteorological observations from nearby weather stations. On these days, or just before them, it rained.

The uneven distribution of precipitation and its effect on vegetation can also be traced from radar images, which is a topic for a separate study. It is recommended to exclude dates with abnormally high values when analyzing the course of vegetation.

In the "radar NDVI" image, the influence of humidity is not so pronounced. According to the "radar NDVI" course graphs, you can follow a natural trend in the development of winter crops. The maximum amount of green biomass observed in winter crops at the end of May-beginning of June (entry into the tube, earing) corresponds to the minimum values of the "radar NDVI".

In Fig. 9 shows graphs of the growing season for spring wheat. Increased values also draw attention to themselves intensities dispersions radarnogo the signal, appropriate for rainy days. Of interest is the progress graph of the "radar NDVI". Just like for winter crops wheat, here the inverse relationship between the volume of biomass and the intensity of the radar signal is characteristic. Lowest values of "radar NDVI" they fall at the beginning of July, which, as in the case of winter crops, corresponds to the maximum values of biomass. The growing season schedules for spring barley are generally similar to those for spring wheat.

Sunflower growing season schedules are very different from those for cereals

Figure 8. *Intensity of radar signal scattering by winter wheat crops:*
a) Time series of signal intensity in the VV polarization;
b) Time series of signal intensity in the VH polarization;
c) Radar NDVI time series

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crops (fig. 10). The increase in biomass and the associated flowering and fruiting processes cause increased values of the radar signal scattering intensity in August (in both polarizing modes, especially in VH).

"Radar NDVI", in contrast to grain crops, not allows locate of any explicit ones patterns. Fields under with corn they show a steady downward trend in the "radar NDVI" values as they grow and mature.

The conducted research allowed us to draw the following main conclusions:

- Sentinel-1 radar images are suitable for regular space monitoring.

productions.

Images are guaranteed to be received at the specified time, which ensures regular observations. There is no risk of missing data due to cloud cover and poor light conditions. Image quality can be significantly affected by many external factors, primarily soil and vegetation humidity.

- Decoding of the main groups of agricultural crops based on Sentinel-1 radar images is possible. The conducted research showed the possibility of confident recognition of individual groups of cultures with the possibility of mathematical description of their decryption features. It is possible to develop an algorithm for automated decoding of certain types of agricultural crops

- Biophysical parameters of growth and development of agricultural vegetation require further in-depth study. Necessary comparison of data on scattering intensity and "radar NDVI" with phenological phases of vegetation development.

-

It is possible to confidently identify
certain stages
of agricultural technological work in the fields, such as harvesting.
Thus,

the Sentinel-1 images certainly have the potential to solve some of the tasks of monitoring agricultural land
.
The research conducted at Sovzond is based on the following criteria:

Figure 9. *Intensity of radar signal scattering by spring wheat crops:*
a) Time series of signal intensity in the VV polarization;
b) Time series of signal intensity in the VH polarization;
c) Radar NDVI time series

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b
in

one of the first in Russia to describe the capabilities of Sentinel-1 data for solving agricultural problems. In the course of the study, new tasks were formulated for further research. At the same time, we can already talk about automating individual processes of preprocessing remote sensing data Sentinel-1 on the basis of web service the company Sovzond " Geoanalytics.Agro". The generated products allow you to perform visual decoding of crop composition, visually assess the degree of moisture content, and track the progress of agrotechnological work directly in the web service interface.

On April 22, 2016, a second satellite, Sentinel — 1B, was launched into orbit. It is expected that with the launch of the second satellite, the frequency of shooting will be reduced to 5 days, which will allow you to get even more images during the growing season.
season, ensuring the stability and reliability of space monitoring.

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Figure 10. *Intensity of scattering of the radar signal by sunflower crops:*
a) Time series of signal intensity in the VV polarization;
b) Time series of signal intensity in the VH polarization;
c) Radar NDVI time series

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