Processing data from Russian meteorological satellites to solve agricultural problems

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Abstract. This paper describes the procedures for preliminary and thematic processing of satellite data in the Far-Eastern Center of State Research Center for Space Hydrometeorology «Planeta» for their use in agricultural tasks. A brief description of cross-calibration procedures for the MSU-MR («Meteor-M» No. 2) and MSU-GS («Electro-L» No. 2) instruments and atmospheric correction for the MSU-MR instrument is given. The importance of these procedures for obtaining thematic products, such as maps of cloud and snow cover, as well as vegetation indices, which are actively used in the analysis and problem-solving for agricultural tasks, is indicated. Far-Eastern Center of State Research Center for Space Hydrometeorology «Planeta» plans to further develop the procedures for preliminary and thematic processing of information from Russian satellite instruments of low and medium resolution, which would increase the potential for the use of satellite data for agriculture.

1. Introduction

Agriculture determines the food security of the population. Agribusiness success, efficient resource management and planning in the agricultural sector are impossible without information on crop yields. Satellite monitoring in agriculture is becoming increasingly popular compared to other types of monitoring as it is more efficient and reliable, offers better frequency, uniformity, visibility.

Satellite monitoring in agriculture is a complex of measures for obtaining thematic products for: yield evaluation; identification of the type of cultivated crops; early assessment of hydro-meteorological conditions and prediction of its possible impact on agricultural land, etc. To solve applied problems of agriculture, Far-Eastern Center of State Research Center for Space Hydrometeorology «Planeta» (hereinafter – FEC SRC «Planeta») produces such products as vegetation index maps, fire condition maps, snow cover maps and several others.

FEC SRC «Planeta» is a leading Far Eastern organisation engaged in the operation and development of Earth observation systems from space. The Centre has its own systems for receiving, processing and analysing satellite information, extensive archives of data of hydro-meteorological, natural-resource and oceanographic significance. To solve some agricultural problems, it is necessary to analyse datasets spanning over several years, which requires high productivity and processing power of processing systems. Studies to evaluate the efficiency of using modern hybrid computing systems for processing and analysis of satellite data were conducted, using the resources of a digital computing platform based on the OpenPOWER architecture [1], by the center’s employees together...
with the employees of the Computing Centre of the Far Eastern Branch of the Russian Academy of Sciences.

Until recently, the FEC SRC «Planeta» was using information from foreign satellites, having developed reliable and effective systems and complexes for preliminary processing of satellite data. These include methods such as calibrating the reflectance, masking the cloud cover, and atmospheric correction. Preliminary processing is necessary, since in its absence the satellite data will be incorrect, and thematic products obtained from the results of calculations will have an error. In recent years, with the expansion of the Russian hydro-meteorological satellites groups of the Meteor-M and Electro-L series, it became necessary to process the obtained data for satellite monitoring tasks, including in agriculture.

This paper concentrates on the pre-processing and thematic processing procedures used in the FEC SRC «Planeta» for Russian satellites of low- and medium-resolution, as well as the prospects for their development for agricultural purposes.

2. Pre-processing procedure

The reliability of the information obtained from satellite instruments depends on the accuracy of measuring the spectral reflective characteristics of natural objects on the earth's surface. To improve the accuracy of measurement, it is necessary to check the stability of the characteristics of satellite instruments. One of the main methods of such verification is the absolute calibration of the instruments. Initially, the equipment is calibrated before the launch of the satellites – however, during launch or extended orbital operation, control settings or photodetector sensitivity may degrade, which would affect the accuracy of measurements [2]. One of the options for obtaining reliable data from the satellite is cross-calibration of the equipment using the data of other satellite instruments, where the measurements are constantly adjusted, their delta level is known and stable. The FEC SRC «Planeta» routinely runs cross-calibration [3-5] a low-resolution multi-spectral scanner (hereinafter – MSU-MR) [6] data, which installed on «Meteor-M» № 2 satellite, as well as a data of multi-spectral scanner for a geostationary satellite «Electro-L» № 2 [7] (hereinafter – MSU-GS). An example of cross-calibration for the MSU-MR data is shown in figure 1.

![Figure 1. Colour representation of the value of the humidity index: a) AVHRR («Metop-A» satellite); b) MSU-MR before cross-calibration; c) MSU-MR after cross-calibration.](image)

The result of cross-calibration are linear regression coefficients, which allow the operator to recalculate the reflectance in the first three channels (channels covering the visible spectrum of electromagnetic radiation and near-infrared range) of the MSU-MR and MSU-GS instruments. Using the example of the humidity index (figure 1), it can be seen that, prior to cross-calibration, its values lie in the range of -0.2 – 0 and do not correlate with the values calculated according to the data of the AVHRR instrument, which is taken as a reference due to similar spectral characteristics with the MSU-MR. After cross-calibration, a visual matching of the values of the humidity indices is observed. Thus, cross-calibration ensures adjustment of the measurements in the channels of the satellite instrument so that they correspond to the real spectral characteristics of the observed objects.

The cross-calibration procedure allows for the preparation of data for further use in thematic processing tasks. However, there are tasks that are highly sensitive to atmospheric influence, for example, calculating of vegetation indices or plotting the river flood vectors. When passing through the atmosphere, recorded by the satellite electromagnetic radiation is attenuated due to the effects of
absorption and scattering by aerosol particles and molecules of small gas components. This can result in a distorted representation of the spectral characteristics of the observed objects, and, as a consequence, to incorrect plotting of thematic products. To compensate for the atmospheric impact on the resulting signal that is recorded by the satellite, an atmospheric correction (hereinafter – AC) procedure is carried out.

In FEC SRC «Planeta», the AC task for the data of the MSU-MR instrument is solved using the method based on the use of Lookup Tables (hereinafter – LUT) [8]. These tables contain information about the reflectance of the underlying surface for each spectral channel of the MSU-MR satellite, depending on the observation conditions and the state of the atmosphere. The LUT was plotted using the Second Simulation of a Satellite Signal in the Solar Spectrum (6S) radiation transfer model [9]. Using LUT, a transition is made from the values of the radiance measured from the satellite at the top of the atmosphere to the reflectance.

During the validation, reflectance of the underlying surface of the test sites according to the European Organization for Satellite Meteorology EUMETSAT «Surface Albedo Validation Sites» [10] were used as reference values. After the AC procedure, ~5% increase in the correlation with the reference values is observed. Figure 2 shows the result of AC on the example of a multi-spectral image from MSU-MR instrument.

![Figure 2. A multi-spectral image from MSU-MR: a) before atmospheric correction; b) after atmospheric correction.](image)

When analysing the information from figure 2, it is worth noting that before the AC the image has a greenish-yellow hue – this is a consequence of the atmospheric presence of a certain concentration of ozone, water vapour and trace gases, which are the main contributors to the reflectance distortion of the underlying surface. The post-AC image no longer contains this hue. This is because the AC procedure neutralised the influence of the atmosphere.

3. Thematic products

The pre-processing procedure allows for preparation of data for its subsequent thematic processing. FEC SRC «Planeta» on an ongoing basis provides a wide range of thematic products using the data of the MSU-MR satellite instrument [11, 12]. From this list of products, maps of cloud and snow cover, as well as vegetation indices are used also for agricultural needs. Snow cover map gives the operator an opportunity to assess the distribution of snow over the territories and to predict possible flooding during the snowbreak. Cloud cover maps make it possible to calculate cloud parameters, which then can be used by meteorologists for near real-time information weather phenomena that are potentially hazardous to agricultural land. Calculation of vegetation indices provides for tracking the dynamics of growth and ripening of crops.

To solve agricultural problems, the highest possible accuracy is required when analysing the reserves and distribution of snow cover, the timing of dangerous weather phenomena. In this regard, the FEC SRC «Planeta» is constantly working to improve the calculation algorithms for such thematic products.

To solve the problems of classification of cloud and snow cover, the FEC SRC «Planeta» uses machine learning methods based on convolutional neural networks (hereinafter – CNN) [13]. The classification issues are solved on the basis of previously created datasets, including samples of
various types of surfaces with an indication of their belonging to a particular class. The datasets consist of textures, where the size was selected experimentally depending on the spatial resolution of the instrument, the accuracy of the classification, the speed of the algorithm and other conditions. Each texture includes a set of instrument channels that allow one to distinguish between the classes of snow, cloud cover, land or water. An example of a mask of cloud and snow cover is shown in figure 3. It is worth noting that agricultural tasks do not require the detection of cloud cover over the marine territory, therefore, in the finished product, the cloud class above the water is not calculated.

Validation of the results obtained using manual decryption of images by the operator and comparison with cloud masks according to the data from the VIIRS instrument installed on the satellites Suomi-NPP and NOAA-20 showed high accuracy of cloud detection against the background of snow and water, as well as relatively high noise immunity. Most of the erroneous classifications are related to cases of translucent cirrus cloud cover, through which the underlying surface is clearly visible.

Given that the basic information about the nature of objects on the Earth's surface is contained in their spectral characteristics, maps of vegetation, water, snow, and other indices are used to work with spectral information. Based on a combination of brightness values in certain channels of the satellite instrument, by calculating the required index, the operator gets the information necessary for identifying the object under study. Next, images corresponding to the index value in each pixel are constructed, which allows the operator to separate one object from another and evaluate its condition. The main thematic product used for tracking the dynamics of vegetation growth is the Normalized Difference Vegetation Index (NDVI) [14]. It is calculated using the previously obtained cloud mask, since it is required only for a cloudless underlying surface. Figure 4 shows the coloured NDVI for the southern part of Sakhalin island, before and after the AC procedure.

![Figure 3](image1.png)  
**Figure 3.** An example of a mask of cloud and snow cover: a) a multi-spectral image from the MSU-MR instrument; b) a map of cloud and snow cover.

![Figure 4](image2.png)  
**Figure 4.** Coloured NDVI representation: a) comparison area (according to Google Maps); b) MSU-MR before atmospheric correction; c) MSU-MR after atmospheric correction.
Analysing the NDVI index information from figure 4, it can be noted that its values before and after the correction differ significantly. In the selected NDVI zone the AC assumed values of 0.3-0.4, which in practice corresponds to sparse shrub vegetation [15]. After the AC, NDVI takes on the values 0.55-0.65, which in practice corresponds to a mixed forest, which is what the selected area represents. This confirms the validity of AC when applied to satellite data for the accurate calculation of vegetation indices. The analysis of smaller components of the Earth's surface, such as fields, rivers, etc., requires the use of medium-resolution data, for example, from a complex of multi-spectral satellite imagery (hereinafter – KMSS) [16]. FEC SRC «Planeta» uses the data from this instrument for plotting the overview maps and the vectors of river floods. River floods, especially during high water period, have a profound effect on agricultural land, because such phenomena can be lost completely or partially destroy the crops. The use of cloud cover masks and the AC, developed at the FEC SRC «Planeta» for KMSS, will ensure full automation of the process of building the products. In addition, the use of AC provides for the calculation of vegetation indices. Given the KMSS spatial resolution (50 m per pixel), the analysis of indices will allow a more qualitative and detailed analysis of agricultural land.

4. Conclusion
In this paper, we consider the satellite data pre-processing procedures developed at the FEC SRC «Planeta». The paper describes the cross-calibration of the short-wave channels of MSU-MR and MSU-GS instruments, the plotting of cloud and snow masks, and AC application to the data obtained from the MSU-MR instrument. These procedures ensure more accurate calculation of data products, including for agricultural needs. The Far Eastern FEC SRC «Planeta» plans to further develop the procedures for preliminary and thematic processing of information from Russian instruments of low and medium resolution, which would increase the potential for the use of satellite data for agriculture.

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