Decryption of snow cover on space images in spring period

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Abstract. The article is devoted to a comparative analysis of the results of snow cover interpreting on satellite images using various software tools on the example of individual basins in the catchment area of the Votkinsk Reservoir. Space images were decoded in ArcGIS and MultiSpec using the methods of interactive supervised classification with training and maximum similarity, and in the ScanEx Image Processor software - using NDSI and NDFSI indices. It was found that the use of the NDFSI index increases the accuracy of determining the areas occupied by snow for forested parts of the catchment by an average of 30%.

1. Introduction
To predict the volume and duration of spring floods, a reliable estimate of the maximum snow storage, daily values of air temperatures, precipitation during the melting snow cover, etc., over the catchment area in spring is essential [3].

In this regard, it is extremely important to know the snow cover spatial distribution and its changes during the period of snow melting within the river basins. This information can be obtained from Earth remote sensing data.

Currently, on the Internet [1, 4] there are a large number of digital space images. First of all, there are available catalogs with information about the existence of images of a certain type in the investigated area, which make it possible to assess their quality using a reduced viewing image.

One of the most common sources is the Terra EOS satellite with a MODIS scanning spectroradiometer [8, 18]. Photographing of the Earth's surface is performed every 2 days in 36 spectral zones (in the range of 0.405-14.385 microns) with a pixel resolution of 250-1000 m and is stored in the NASA archive [16], which provides information on a global and regional scale.

Various software packages to view, process and interpret digital space images are used.

The aim of the paper – a comparative analysis of the results of snow cover decryption in spring period on satellite images using a variety of software products.

The study on the example of the catchment area of the Votkinsk Reservoir (figure 1) with a total area of 184240 km² was carried out. This catchment covers the basin of the Upper and Middle Kama and located in the northeast of the European part of Russia. The length from north to south is 640 km (61°57' N – 56°05' N), and 530 km from west to east (51°35' E – 60°27' E).

About 80.5% of the catchment area is in the Perm Territory. The northern part is located on the territory of the Komi Republic, the western part – on the territory of Udmurtia Republic and the Kirov Region, and the southeastern part – in the Sverdlovsk Region [2]. The right-bank part of the catchment is located on the Russian Plain, the left-bank part – on the Western Urals [7].
The greatest amount of precipitation falls on the ridges and slopes of the mountains (1000-1200 mm). In the Middle Urals, the annual precipitation amounts to 800-900 mm, and in the southern part – 600-700 mm. In the rest of the territory, precipitation decreases from north (250 mm) to south (200 mm), increasing only in the regions of the Upper Kama Upland and the Sylva's Ridge [10]. Most of the precipitation from 66 to 77% falls in the warm half of the year, the rest accumulates during the winter.

The catchments to research: plain – Kosa-Kosa (A = 6184 km²) and Kama-Gayny (A = 27630 km²); mountainous – Vishera-Ryabinino (A = 30900 km²) (figure 1).

Figure 1. The catchment area of the Votkinsk Reservoir [2].

2. Materials and methods
To determine the changes in the snow cover in the study area during the snow melting period, digital satellite images, obtained from the Terra satellite with a spatial resolution of 500 m, were used. The Terra satellite flies over the Perm Territory from 7.00-8.00 UTC (Coordinated Universal Time) [16], which in the spring period corresponds to 12.00-13.00 local time. Therefore, it is always possible to select images from the NASA archive for the studied area.
For three years there were selected the images in such a way that, on the one hand, they would cover the entire period of snow melting, and on the other, they would be characterized by minimal cloudiness (table 1).

**Table 1. MODIS images used for decryption spatial distribution of snow cover.**

| Years | Shooting dates          | Number of shots |
|-------|-------------------------|-----------------|
| 2002  | 03.04, 13.04, 20.04, 24.04, 26.04, 28.04, 29.04, 30.04, 01.05, 05.05, 15.05, 13.06 | 12              |
| 2010  | 05.04, 09.04, 17.04, 21.04, 22.04, 25.04, 08.05, 11.05 | 8               |
| 2015  | 03.04, 05.04, 15.04, 28.04, 30.04, 03.05, 04.05, 07.05, 10.05, 11.05 | 10              |

Currently, there are a number of software tools used for preliminary processing of satellite images. This study used both commercial ArcMap software (the central application of the ArcGIS) and ScanEx Image Processor, as well as the free MultiSpec software.

ArcMap is the application use for creating, editing, displaying, and exploring geodatasets. The ArcMap application has the ability to process satellite images based on classifications using training samples [15, 17].

ScanEx Image Processor is software for visualization, advanced analysis and thematic processing of optical and radar survey data.

MultiSpec is a software package specially designed for interactive analysis of multispectral images of the earth's surface obtained by various imaging systems [6].

In the ArcMap program, the space image was interpreted using interactive controlled classification and maximum similarity classification. Using the Image Classification toolbar, training samples, each of which corresponded to a specific class were created. Interactive learning classification is performed with a resolution corresponding to the current layer [9]. It should be noted that when using interactive supervised classification, the reliability of the results depends on how correctly the reference areas are selected.

3. Results and discussion

The computer interpretation of the initial satellite images was performed using the methods of interactive and maximum similarity classifications (figure 2). On their basis, raster images, which make it possible to further determine the values of the fraction (%) of the catchment area occupied by snow were obtained.

Decoding of a multichannel image in the MultiSpec program (figure 3) is also based on the classification with training similar to the ArcMap program. The accuracy of the interpretation results obtained on the basis of classification methods largely depends on the season, time of day, etc. [9].

When compiling training samples, it should be borne in mind that the presence of snow in open treeless areas is determined with great reliability. At the same time, the accuracy of determining the area of snow cover for forested catchments is much lower [5].

The ScanEx Image Processor software allows you to automatically create both the cloud and the snow masks. The area occupied by snow is determined based on the calculation of the NDSI (Normalized Difference Snow Index) [11], which is calculated as the ratio of the difference between the reflection coefficients of radiation $P$ with a wavelength of $\lambda_{\text{GREEN}} = 555$ nm and $\lambda_{\text{SWIR}} = 1640$ nm to their sum (1):

$$NDSI = \frac{(P_{\lambda_{\text{GREEN}}} - P_{\lambda_{\text{SWIR}}})}{(P_{\lambda_{\text{GREEN}}} + P_{\lambda_{\text{SWIR}}})}.$$  

Visible radiation in the green zone of the electromagnetic spectrum is recorded in the 4th channel, and short-wave infrared radiation in the 6th channel.

A satellite image is a discrete (pixel) image, so all calculations are performed for each pixel. A pixel is considered covered with snow if: the NDSI value is greater than or equal to the NDSI threshold value (default 0.4); the radiation value on the sensor in the 2nd channel ($\lambda_2 = 858$ nm) is greater than
the value of the 2\textsuperscript{nd} channel threshold (default 0.11); the radiation value on the sensor in the 4\textsuperscript{th} channel is greater than the threshold value of this channel (default 0.10) [11].

\begin{figure}
\centering
\includegraphics[width=\textwidth]{image1.png}
\caption{The result of the classification of the multichannel image in the ArcMap program as of 17.04.2010 (on example of the Vishera-Ryabinino catchment): a – the original image; b – according to the method of interactive controlled classification; c – according to the method of maximum similarity.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{image2.png}
\caption{The classification result of a multispectral image in the MultiSpec program on 04.05.2015 (on example of the Kama-Gainy catchment).}
\end{figure}
It should be noted that the $NDSI$ is an effective indicator for mapping snow cover on a large scale, but in forested areas the accuracy of snow identification using this index is reduced [11-14]. Therefore, the value of the $NDSI$ index for snow-covered forest areas varies in a wide range from 0 to 0.9. This is due to the low reflectivity in the visible range of the spectrum.

Since the reflection coefficient in the infrared zone of the spectrum is high, it will increase in snow-covered forest areas, which makes it possible to determine the snow cover in forest areas with greater accuracy. For this purpose, in [11], a new index $NDFSI$ (Normalized Difference Forest Snow Index), which is the ratio of the difference between the reflection coefficients of radiation $P$ near infrared (NIR) and short-wave infrared (SWIR) to their sum (2), was proposed:

$$NDFSI = \frac{P_{\lambda\text{NIR}} - P_{\lambda\text{SWIR}}}{P_{\lambda\text{NIR}} + P_{\lambda\text{SWIR}}} \quad (2)$$

The value of the $NDFSI$ index for snow-covered forest areas varies in a much smaller range from 0.40 to 0.65 [13].

Thus, in order to improve the accuracy of determining the spatial distribution of snow cover and its change during snow melting within forested river basins, it is necessary to use the $NDFSI$ index instead of the $NDSI$ index when calculating the snow mask.

Using $NDFSI$ index helped to clarify the definition of the catchment's share covered by snow (table 2). This is especially important for the second half of the snowmelt period, when the area's difference increases to 30-65%.

### Table 2. Changes in the catchment share covered by snow during the snow melting period, calculated using indices $NDSI$ and $NDFSI$ (on example of the Kosa-Kosa catchment)

| Date       | The catchment's share covered by snow, % | $NDSI$ index | $NDFSI$ index | Inaccuracy $\Delta$, % |
|------------|----------------------------------------|--------------|---------------|------------------------|
| 03.04.2015 | 99.83                                  | 95.90        | 4.10          |
| 05.04.2015 | 78.23                                  | 84.60        | 7.53          |
| 15.04.2015 | 80.61                                  | 91.80        | 12.19         |
| 28.04.2015 | 50.61                                  | 80.90        | 37.44         |
| 30.04.2015 | 15.50                                  | 42.20        | 63.27         |
| 03.05.2015 | 14.54                                  | 26.20        | 44.50         |
| 04.05.2015 | 0.00                                   | 0.00         | 0.00          |
| 06.05.2015 | 0.00                                   | 0.00         | 0.00          |

Let's consider what results of decryption are given by classification methods in ArcMap and MultiSpec programs in comparison with ScanEx Image Processor. For this, a comparative analysis of snow cover area changes in the Vishera-Ryabinino catchment in the spring period was carried out (Figure 4).

The use of MultiSpec software and ArcMap application significantly reduces the area of snow cover, especially at the beginning of the snowmelt period, compared to ScanEx Image Processor (Figure 4). It should be noted that the use in the calculations of the reflection coefficients of incident radiation in the near infrared and short-wave infrared zones of the electromagnetic spectrum ($NDFSI$ index) makes it possible to determine the snow cover of the catchment area in the most detailed way and take into account the fallout of solid atmospheric precipitation during the snow melting period.
Figure 4. Snow cover area changes in the Vishera-Ryabinino catchment in the spring period.

4. Conclusion

To determine the area of snow cover, the method of interpreting space images is of great importance. A significant role in the classification using training samples is played by the "human factor", which reduces the representativeness of the information obtained about the snow cover of the territory under tree crowns or closed clouds. An automated method for determining snow cover, based on the use of various properties of the electromagnetic spectrum (NDFSI index), makes it possible to determine the presence of snow with the greatest accuracy.

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