SES 2018
Fourteenth International Scientific Conference
SPACE, ECOLOGY, SAFETY
7 – 9 November 2018, Sofia, Bulgaria

MONITORING OF SHORT-LIVED SNOW COVERAGE BASED ON AEROSPACE DATA ON SVALBARD IN NORWAY

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Keywords: *climate changes, remote sensing, SAR images, wet snow coverage.*

Abstract: *The mapping of snow covered areas and wet snow dynamics in the Arctic is important for many applications such as flood forecasting, snow drain modeling, water supply for irrigation and hydroelectric power plants, weather forecasts, and climate change understanding. Year-round snow cover monitoring through land surveys is almost impossible in the Svalbard area, aerial photography surveys are also insufficient due to the specific conditions of sunshine. Due to the presence of cloud cover and different climatic conditions, the snow cover information is insufficient or very limited. Microwave images have the advantage over visible and NIR techniques as they are sensitive to changes in surface moisture and thus provide useful information about changes in their physical states. The study evaluates the usefulness of C-band SAR images for data mining only for wet snow from other surfaces, but also uses optical indices and indicators. TCT (Tasseled Cap Transformation) was used as a moisture indicator, as well as NDVI (Normalized Difference Vegetation Index), which was used to quantify the presence or absence of vegetation during wet snow periods or after melting.*

The subject of the study is the dynamic during the different seasons in Svalbard, Arctic. The objects were analyzed and mapped according to the European Space Agency (ESA) data acquired by sensors Sentinel-1 SAR, Sentinel 2 MSI and GIS. Results have been obtained for changes in snow coverage during the spring-summer transition and its dynamics. The data used is with high time-spatial resolution, which is an advantage when looking at the snow cover. The changes of the environmental objects are shown with different processing approaches. The results clearly show that snow melting can be registered by using SAR data via different polarization, TCT and NDVI. The effect of the research on aerospace data and technology enables us to obtain different digital models, structuring and analyzing results excluding the subjective factor.

МОНИТОРИНГ НА МОКЪР СНЯГ ЧРЕЗ АЕРОКОСМИЧЕСКИ ДАННИ В СВАЛБАРД, АРКТИКА

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Ключови думи: *промени в климата, дистанционно наблюдение, радарни изображения, мокро снежно покритие*

Резюме: *Картирането на площите покрити със сняг и динамиката на мокър сняг в Арктика е важно за много приложения като прогнозиране на наводнения, моделиране на оттичането на снеговалежи, водоснабдяване за напояване и водноелектрически централи, прогнози за времето и разбиране (анализиране) изменението на климата. Целогодишен мониторинг на снежната покривка чрез наземни проучвания е почти невъзможна в района на Свалбард, въздушните фотографски проучвания също са недостатъчни, поради специфичните условия на слънцегреенето. Поради присъствието на облачно покритие и различните климатични условия информацията за снежната покривка е недостатъчна или е силно ограничена. Микровълновите снимки имат предимство пред видимите и NIR техники, тъй като са чувствителени към измененията на повърхностната влага и по този начин предоставят полезна информация относно промените в нейните физически състояния. Проучването оценява полезността на С-лентовите SAR (Synthetic Aperture Radar) изображения за извличане на данни само за мокър сняг от други повърхности, но също така използва и оптични данни* *за направа на индекси и показатели. Използвана е TCT (Tasseled Cap Transformation) като индикатор за наличие на влага, а също така NDVI (Normalized Difference Vegetation Index), който е използван за количествена оценка за наличието или отсъствието на растителност по време на период с мокър сняг или след неговото стопяване.*

Предметът на изследването е динамиката по време на различните сезони във Свалбард, Арктика. Обектите бяха анализирани и картографирани според данните на Европейската космическа агенция (ESA), придобити от сензори Sentinel-1 SAR, Sentinel -2 MSI и GIS. Получени са резултати за промени в снежното покритие по време на пролетния и лятния преход. Използваните данни са с висока времево-пространствена разделителна способност, което е предимство при мониторинг на снежната покривка. Промените на природните обекти са показани с различни подходи за обработка. Резултатите ясно показват, че топенето на сняг може да бъде най-добре регистрирано чрез използване на данни за SAR чрез различни поляризация, TCT и NDVI. Ефектът от изследването чрез аерокосмическите данни и технологии позволява получаването на различни цифрови модели, структуриране и анализиране на резултатите, като е изключен субективния фактор.

Introduction

Snow covers a considerable portion of Northern Hemisphere lands during winter. It is the component of the cryosphere with the largest seasonal variation in spatial extent. In fact accumulation and rapid melt are two of the most dramatic seasonal environmental changes of any kind on the Earth's surface (Frei et al., 2012; Spasova and Nedkov, 2017).

According to the National Snow and Ice Data Center (NSIDC) the snow consists of frozen water crystals, but because there is so much air surrounding each of those tiny crystals in the snow cover, most of the total volume of the snow layer from air. Scientists refer to the SWE snow-based water equivalent of snow as the thickness of water that would result from the melting of a layer of snow. The often repeated assumption claims that the snow-to-water ratio is ten to one, but this is not always accurate. The water equivalent of snow is more volatile than most people realize. For example, 25 cm of fresh snow may contain not less than 0.25 cm of water and even 10 cm of water, depending on the crystal structure, wind speed, temperature, and other factors. The majority of the new snowfall has a water-snow ratio of between 0.04 (4 percent) and 0.10 (10 percent), depending on the weather conditions associated with the snow.

Wet snow differs significantly from dry snow. Wet snow also has a darker surface or a lower albedo (Picture 1, NSIDC).

Picture 1. Terrain picture in Longyearbyen, 09/06/2018. Author: Temenuzhka Spasova

According to NSIDC for short-term snow or wet snow cover, it is determined that seasonal snow is considered snow that accumulates within a season or snow that lasts only for one season (NSIDC, Meier, 1980).

Hiltbrunner et al., 1997 make extensive identification of the electromagnetic spectral characteristics and omissions in the snow data associated with microwave and optical measurements. Active microwave signatures are made by Ulaby and Dobson, 1989. The statistical behavior of radar measurements carried out by different research groups using different tools is summarized for several categories of terrain. However, only two categories are defined for the snow cover: dry and wet snow. Wet snow is defined as snow with a water content of more than 1 %.

Information on snowfall conditions is of particular interest to the hydrological community. Hydrologists usually want to know how much water is stored in the pool in the form of snow. Hydrologists also deal with the distribution of snow in the area, its condition and the presence of liquid water in it. Generally, all of these snow indicators are difficult to measure and will likely vary widely from point to point (WMO CHy-14, 2012). In order for snow data to be similar, it is necessary to use satellite data.

Climate change can affect how much snow will fall and affect the time of the winter snow season. Between 1966 and 2018, the amount of land and sea ice covered by snow each year decreases in many regions of the Northern Hemisphere, especially during the spring snowfall season. Scientists are modeling how Earth's climate can change over the next 100 years, and the results show that the snow will cover less the planet, especially in Europe and Asia. Climate warming can reduce snowfall and cause earlier spring melting and a shorter snowflake season (NSIDC).

As one of the first, NDVI (Rouse et al., 1973; Tucker, 1979) is one of the most commonly used biomass estimators for green vegetation, as well as remote assessment of vegetation restoration processes after any kind of events like floods and fires (Barton and Bathols, 1989; Lawal et al., 2011, Wang et al., 2002).

NDVI is a numeric indicator that uses the visible and near infrared bands of the electromagnetic spectrum and is considered for remote monitoring and assessment of a given area whether it contains green vegetation or not.

Water is well known to have unique spectral characteristic in the near infrared area, making it completely different from other surface characteristics. Therefore, when it is determined that the surface characteristic is flooded, its NDVI value changes significantly from the usual. Wang et al.,2002 observed that in the lower part of the Yangtze River the value of NDVI for flooded surface characteristics remains negative, whereas the value for non-scratched surfaces is usually greater than 0. However, the choice of this threshold is quite dangerous because river rafting differs greatly from place to place. Therefore the real difficulties in choosing the threshold due to two facts. At the very beginning, the albedo of water bodies is dramatically increased due to the high concentration of precipitations in flooded water. Secondly, the albedo of the uncovered soil decreases significantly due to its high moisture content. Therefore, these two issues together reduce the difference in NDVI values between flooded and dried surfaces. Similarly, based on a number of studies, the NDVI values of flooded water are found to be significantly positive (Barton and Bathols, 1989).

The subject of study in this article is the wet snow in different seasons near the northernmost administrative center in Europe - Longyearbyen, where the population is about 2000 inhabitants. Longyearbyen is located at 78° 13 'N latitude on the west coast of the island of Spitsbergen at the Spitsbergen archipelago, also called Svalbard. The site was selected because of in situ data (Picture 2).

Picture 2. PIcture from drone in Longyearbyen, 09/06/2018. Author: Temenuzhka Spasova

The aim is to demonstrate the use of different satellite data and approaches as wet snow is one of the most dynamically changing natural objects.For the aim of this goal data from ESA (European Space Agency) are used and objects are mapped in different seasons and years.

Due to the nature of the interactions between snow cover and electromagnetic radiation from different frequencies, snow can be distinguished with various instruments such as active and passive sensors (Dozier, 1989; Nolin, 2010, Spasova and Nedkov, 2017).

Fortunately, remote sensing provides recent and up-to-date approaches to studying the dynamics of flooded areas and wet snow, such as differentiated approaches. These approaches can be used not only in small areas, as in classic observation methods, but in vast territories such as the Arctic and Antarctic. It is easy and efficient to register dynamic changes by using data in a different spectral range and combining them with terrestrial data.

The aim is to demonstrate the use of different satellite data and approaches, as wet snow is one of the most dynamically changing natural sites. ESA data are used to achieve the goal and the sites are mapped in different seasons and years.

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Data and methods

1. Selection of indicators and indexes

When different climatic phase transitions occur, different changes occur in the snow and ice sheets, therefore the evaluation indicators also change.

One of the important indexes used in the study is Tasseled Cap Transformation (TCT) (Kauth and Thomas, 1976; Nedkov, 2017) with components Brightness (BR) in R band, Greenness (GR) in G band and Wetness (W) in B band, arranged in RGB model. This type of transformation does not reduce the number of signs in the space of the signs but increases the degree of their identification in the classification of the objects from the land cover (Nedkov, 2017; Spasova, 2018).

The observation of the spectral changes in the melting of snow and wet snow requires the use of different spectral channels. When using SAR images, countless indicators are used which show the degree of humidity change in selected time intervals that have been selected in advance. One of these indicators is the transformed image in microwave decibels and graphical spatial distribution (Spasova and Nedkov, 2017).

Composite images that use two or three dates transformed into dB are also indicators, the information of which shows us the dynamics in wet snow, water and ice. These are the so-called multi-composite images from different time series.

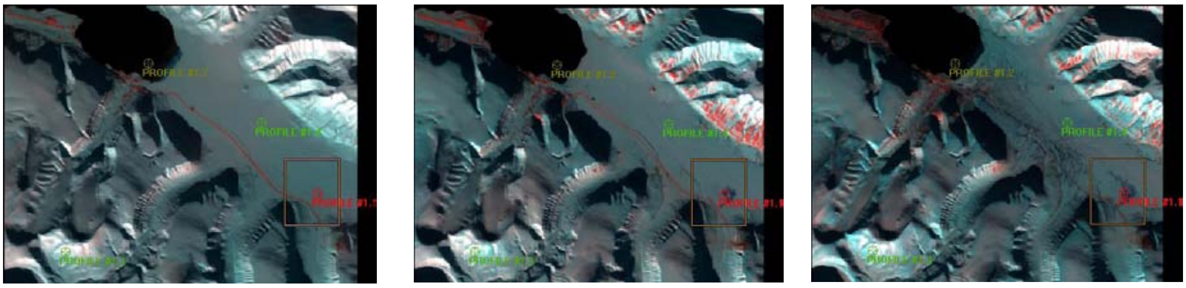
NDVI was used for quantitative assessment of the variations over the different seasons. NDVI is the most commonly used indicator of the state and vitality of vegetation (Tucker and Sellers,1986). NDVI is an indicator of the potential for absorption and reflection of incoming energy from vegetation, its photosynthetic capacity, and the concentration of biomass. It is expressed by the following formula:

(1) $NDVI=(\rho_{(NIR-)}\ \rho_{RED})/(\rho_{(NIR+)}\ \rho_{RED}),$

where ρNIR is the reflection of the radiant energy in the near infrared range of the spectrum and ρRED is the reflection in the red band in the visible range of the spectrum.

2. Selection of test areas and satellite data

Four points in advance are used to test the spectral reflectance of natural objects. Separately, a representative wet snow test area was made.



Sentinel 2A – band 12,8a,4
14/04/2016

Sentinel 2A – band 12,8a,4
12/04/2017

Sentinel 2B – band 12,8a,4
10/04/2018

Fig. 1. Composite optical images from Sentinel-2A and Sentinel-2B with the test areas –bands 12, 8a, 4

The data of the images and the sensors used are shown in Table 1. The test areas have been selected due to available field data, initial visual interpretation of optical images in a suitable composite layout and their spectral characteristics.

Table 1. The used satellite data. Source:https://scihub.copernicus.eu/dhus/#/home

Satellite	Date	Spectral Band, wavelength	Band	GSD*, m
Sentinel-1-A	20/12/2014 22/04/2016 29/04/2017 22/04/201	λ=5,6cm, Polarization: HH,HV,VV Incidence Angel 18°-45°	C	10x10**
Sentinel-2-A	14/04/2016 12/04/2017 10/04/2018 05/06/2017 26/08/2017 06/07/2018 30/07/2018	0.665 µm 0.865 µm 2.19 µm	4 8a 12	10 20 20

*Ground Sample Distance (GSD)

** Pixel Spacing Resolution (rg x az)

3. Methodology

The verification and validation of SAR images have been done using the TCT model and based on pre-selected test areas with ice, wet snow, snow and water from optical images. Selection was performed using ground data from Longyearbyen, located at 78° 13" N, 15° 37" E. Field data are used only for control information to identify the objects and phenomena investigated, as well as the conditions under which these studies are conducted. Ground data is used only in order to calibrate aerospace data (Mardirossian, 2000). Test areas are from non-grounded data.

Coordinates were taken from points with a drone during the arctic summer of June 2018, geometrically attached to Sentinel-2 optical image of 26.08.2017, and three additionally used Ground Control Points in order to georeference all of the SAR images. This is necessary because the optical images are with very high geometrical accuracy, while SAR images require additional corrections and have a different resolution of 11/15, 47/49 and 49/50 meters of pixel size. All of the images are in projection WGS_1984_UTM_Zone_32,33. The selection is then based on Sentinel -2 satellite images, which operate in the optical range and have 13 spectral channels. The spectral curves of each of the test areas (Fig. 2) serve as indicators for data verification. A spectral reflectance curve was made of all of the three images from the spring season.

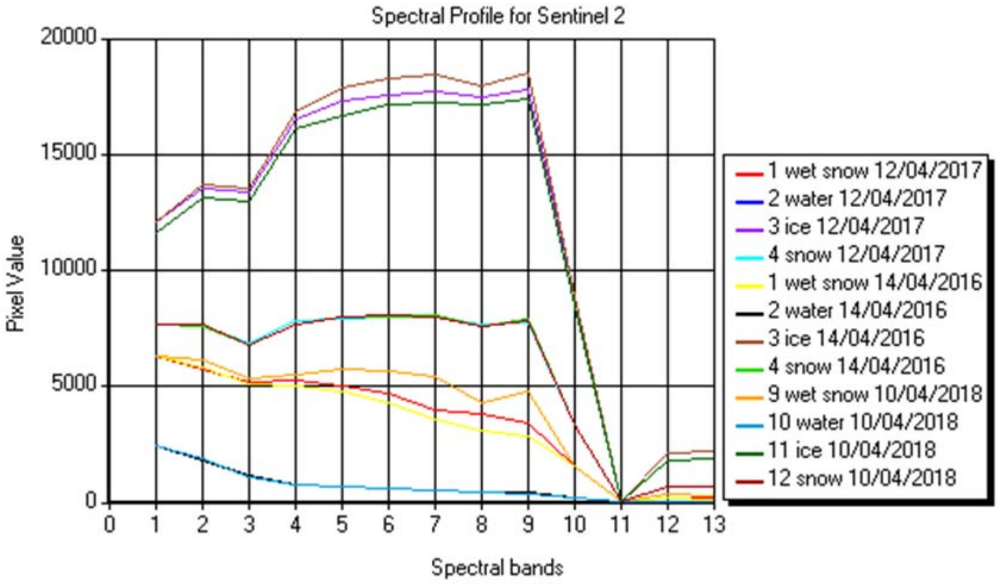


Fig. 2. Spectral characteristics for the test areas

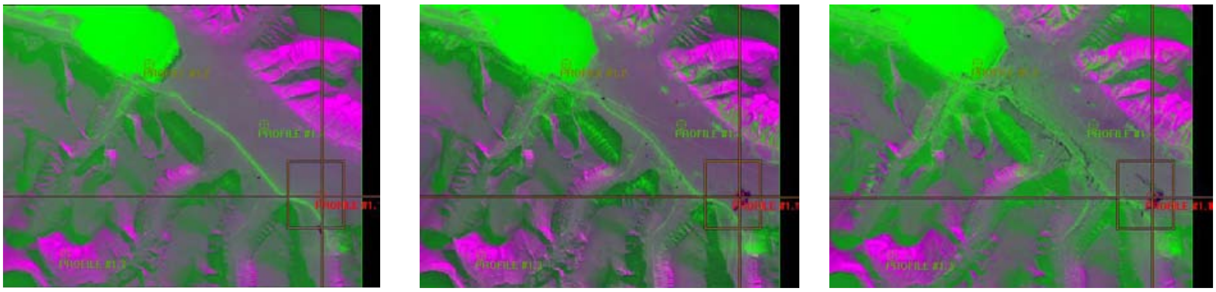
The selected optical images from Sentinel-2 are from one and the same season (Arctic Spring) in three consecutive years from 2016 to 2018. The images from the Arctic Summer of 2017 and 2018 were used in order to interpret the areas better and selected from another season without cloud cover. All of the images were cut using the AOI (area of intrest) of the preselected test areas. The image resolution is 10 m pixel size. After the intermediate image database created, the TCT model was applied to the following images - 14/04/2016, 12/04/2017, 10/04/2018 (Nedkov, 2017). The Sentinel-1 satellite data were selected from the appropriate time series for the Arctic spring and summer periods when the melt process and the time period selected for Sentinel -2 were observed. The data have appropriate orbital characteristics and polarization in the Arctic region - HH (horizontal), HV (horizontal – vertical) and VV (vertical). Pre-selected data cover the period from 2014 to 2018. Each SAR image is cut by AOI (area of interest) and accurately georeferenced to an originally selected date 26/08/2018. In this processing, a first degree polynomial transformation based on three Ground Control Points (GCPs) and Reference GCP on an optical image from 26/08/2018 was performed.

A new database of radar images was created that have the specified test areas. Profiles of spectral area distribution were made from these areas - Spatial reflectance distribution (Spasova and Nedkov, 2017; Spasova, 2018), and then transformation of the SAR images into dB (decibels) was made. The third database of radar images in dB (decibels) was created to validate the data. For a better visualization of places with wet snow, moisture and water, composite SAR images(R-vh,G-vv, B-vh/vv) using dates of different time series and spatial resolution 13 m in dB (decibels) were made.

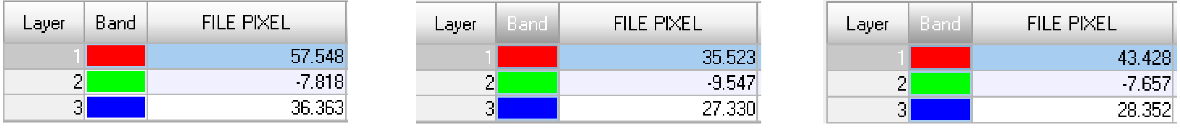
Results

Data from Sentinel-2 MSI can be used to clearly locate the presence or absence of water, snow and ice. Optical images from this area have a lower temporal resolution, making them less suitable for monitoring, as wet snow melts faster. Channels used to detect snow cover and the presence of wet snow are 12, 8a, 4 (Fig. 1), (Nedkov et al., 2016). Extremely accurate are optical images with 10 m resolution for georeference and selection of control points in radar images.They are used to locate test areas, but they are also used to remove cloud cover.

The Tasseled Cap Transformation using the Sentinel -2 optical images (Fig. 3) clearly distinguishes Wetness locations. Even with poor quality, places with wet snow are visible and they are light purple or blue in color between 10 and 30 in band 3, ice places are pink, the green and the blue there are places with water and values below 10. The profile made confirms the presence of wet snow in both years 2017 and 2018, but also visually seen a sharp increase in areas with wet snow on the test areas.



a) 14/04/2016 b) 12/04/2017 c) 10/04/2018

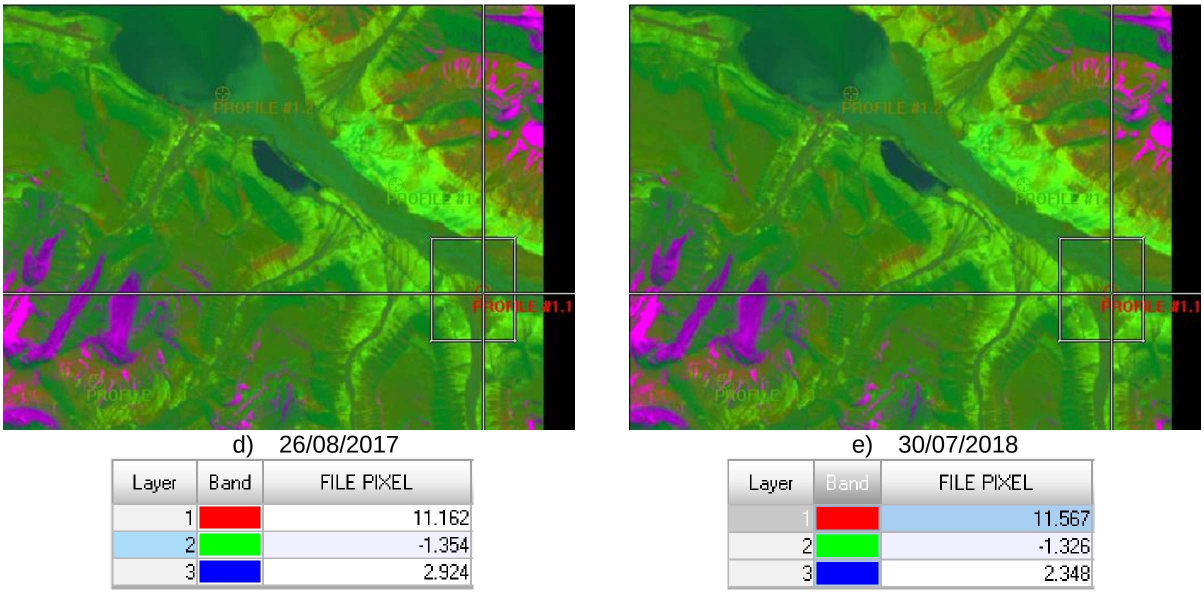


Layer	Band	FILE PIXEL
1	🟥	57.548
2	🟩	-7.818
3	🟦	36.363

Layer	Band	FILE PIXEL
1	🟥	35.523
2	🟩	-9.547
3	🟦	27.330

Layer	Band	FILE PIXEL
1	🟥	43.428
2	🟩	-7.657
3	🟦	28.352

Fig. 3. Composite optical images with Tasseled Cap Transformation profiles, spring



d) 26/08/2017

Layer	Band	FILE PIXEL
1	🟥	11.162
2	🟩	-1.354
3	🟦	2.924

e) 30/07/2018

Layer	Band	FILE PIXEL
1	🟥	11.567
2	🟩	-1.326
3	🟦	2.348

Fig. 4. Composite optical images with Tasseled Cap Transformation profiles, summer

Fig. 4 show the much lower values for the three indicators of soil, vegetation and wetness, and the water clearly stands out in blue. In the third channel of the RGB model, the Wetneess values were measured. There are no wet snow areas, where snow and ice are kept all year round in purple and pink.

NDVI values of about 0.3 are representative for rare plant cover and grass (Fig. 5 and Fig. 6) but not for a healthy forest (Stankova and Nedkov, 2015; Ivanova et al., 2017). This is absolutely true for this area, and the picture of the drone and the terrestrial research confirm it. The upper limit of this index does not exceed a value above 0.796 only during the summer season and occupies a very small part of Svalbard's vast territory. The majority of the April values are around zero, which means moist or wet areas. Values above 0.3–0.4 are extremely small or even single pixel locations.

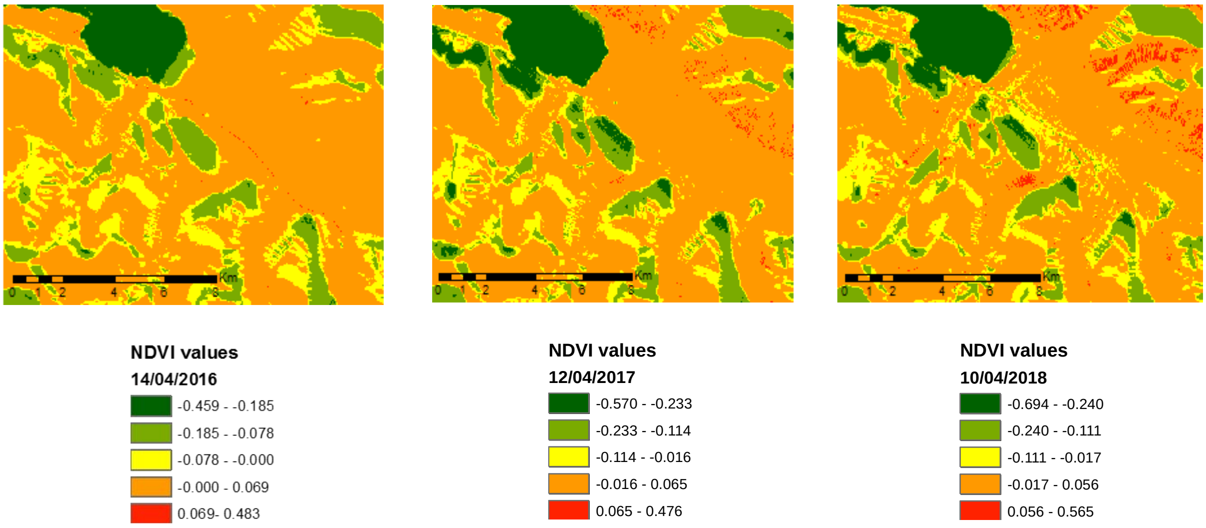


Fig. 5. Spectral index NDVI- spring

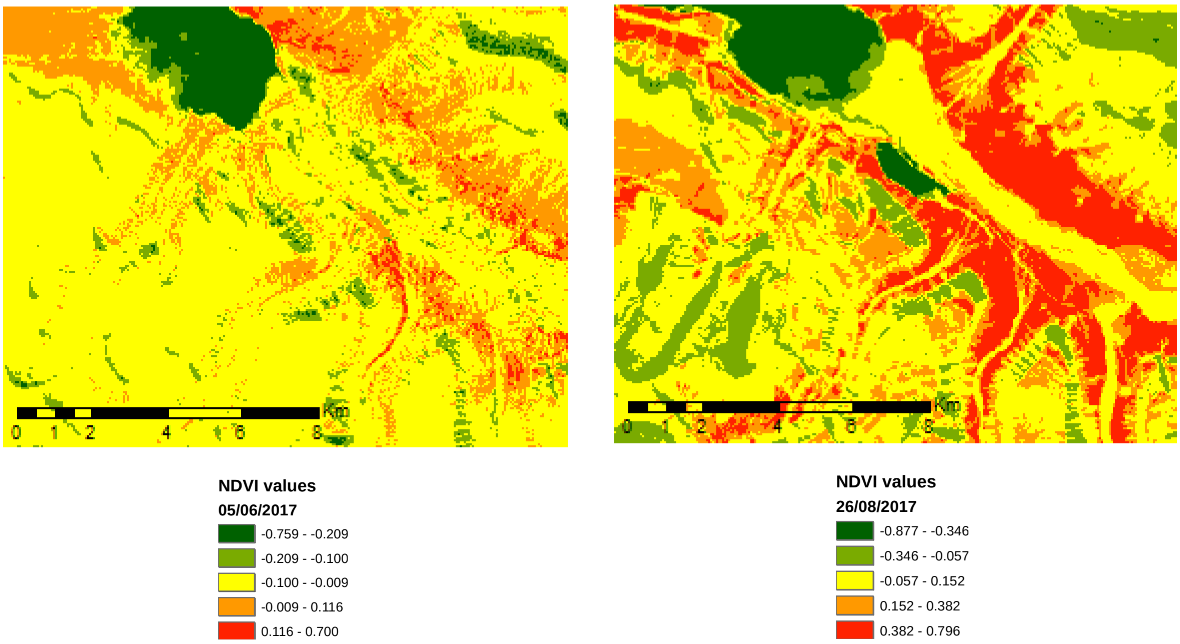
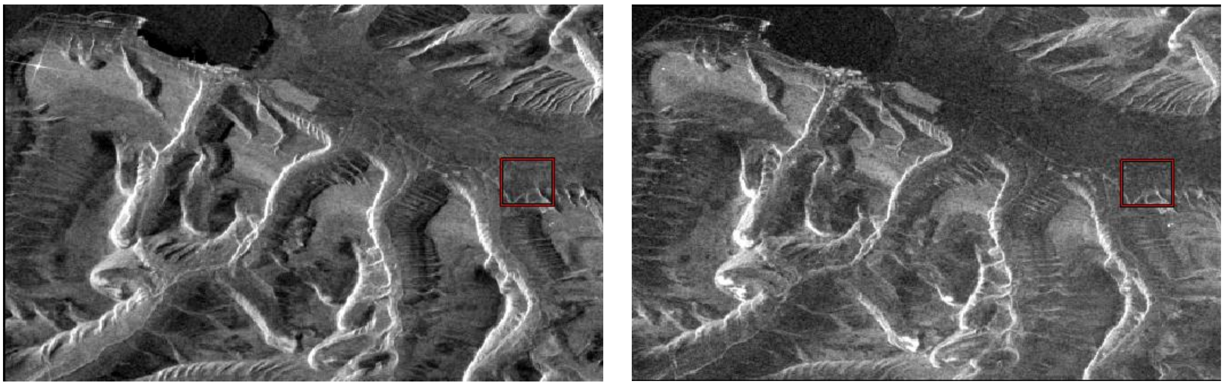


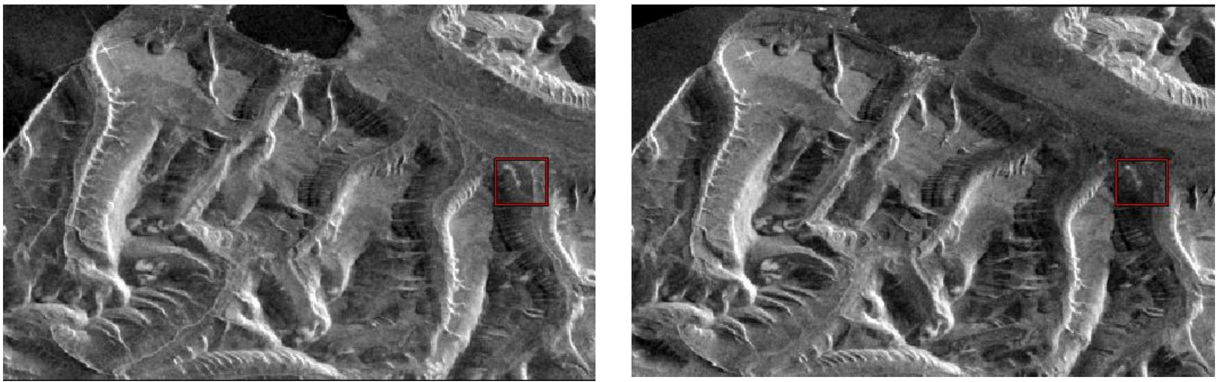
Fig. 6. Spectral index NDVI- summer

The SAR images with hh, hv and vv polarization (Fig. 7 and Fig. 8) from the same period of the year, the spectral and reflectance distribution of wet snow in dB and composite image (Fig. 9) are also a sure way to validate wet snow data and locations. Values between 22 and 28 dB indicate wet snow and a value between 22 and 24 dB in a very humid place, meaning that there are not only wet snow, but also water (Spasova T., Nedkov R. 2017).

During the three years at which the spectral characteristic is made, it shows values typical of wet snow.

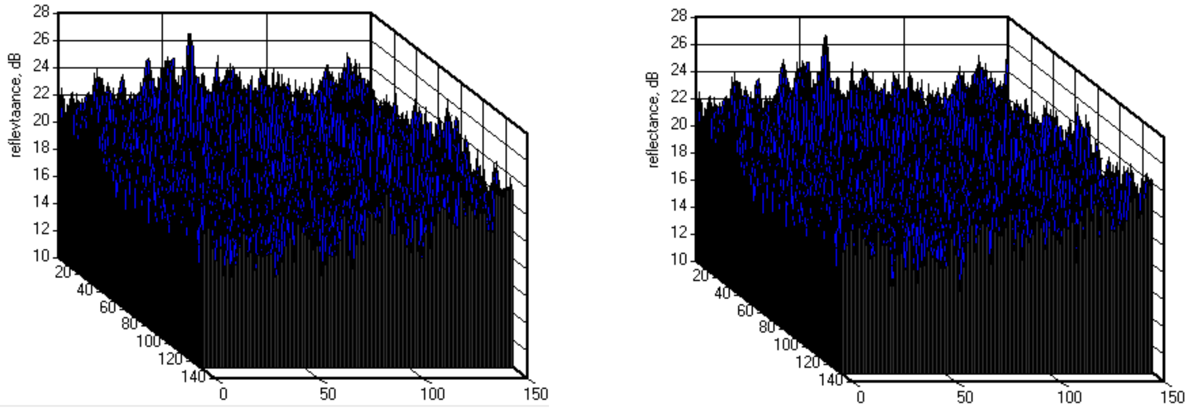


a) Sentinel 1 vv 22/04/2018   b) Sentinel 1 vh 22/04/2018

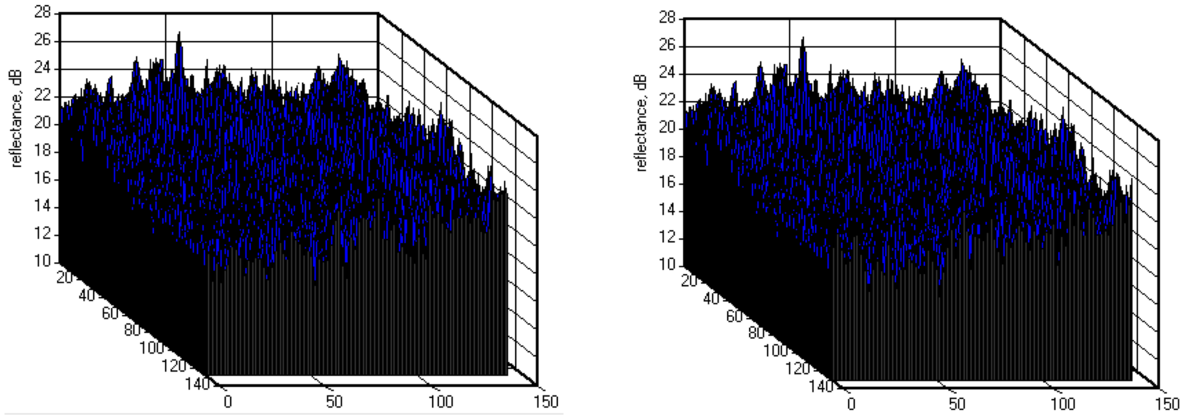


c) Sentinel 1 hh 22/04/2016   d) Sentinel1 hh 29/04/2017

Fig. 7. SAR images with the test areas in dB



a) vv poliarization 22/04/2018 b) vh poliarization 22/04/2018



c) hh poliarization 22/04/2016 d) hh poliarization 29/04/2017

Fig. 8. Spatial reflectance distribution of wet snow in dB

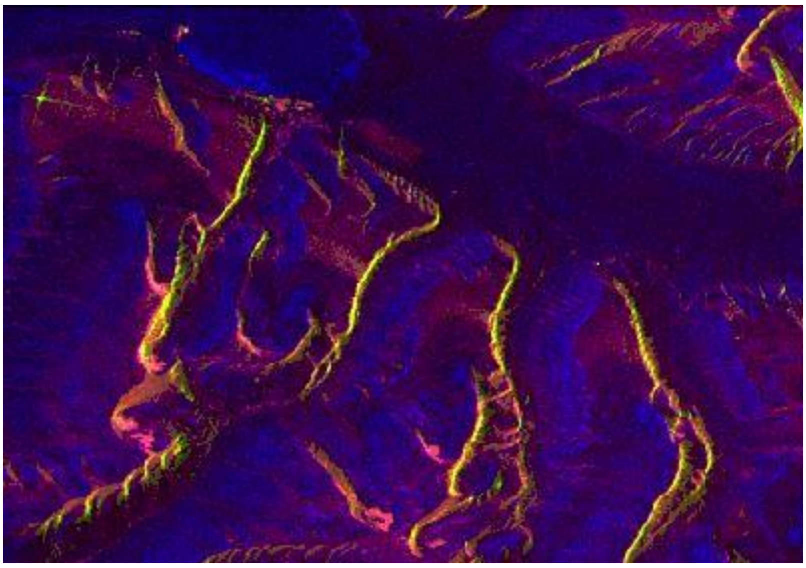


Fig. 9. Composite SAR images from Sentinel -1, 22/04/2018 R-vh, G-vv, B-vh/vv

Conclusion

The use of a differentiated approach and data from active and passive sensors such as Sentinel 1 SAR and Sentinel 2 MSI are extremely reliable when registering wet snow, as it is a very short-term event and is extremely important for climate models. The lack of cloudless images in the summer can be compensated by images from an optical sensor in another season to determine the exact location of the radar image processing.

The complex approach selected for this territory very successfully demonstrates and defines the places with wet snow and their dynamics in a sufficiently representative sample of data. Extremely indicative of surface changes in wet snow is the use of various indices such as NDVI. Surfaces with wet snow in different years show extremely high dynamics for the past year. This certainly speaks of major climate change.

The terrestrial data used also confirms locations with wet snow and lack of vegetation even in June in the Arctic Summer season.

The melting snow and wet snow can be investigated and recorded by the C-band of Sentinel-1, but as an indicator it is necessary to study the wetness from TCT. The lack of qualitative data from an optical image is compensated sufficiently by SAR images, and the use of SAR in dB can be clearly used as a validation method (Spasova, 2017). The resolution and hh,hv and vv polarization in the area is also absolutely sufficient to map the dynamics of wet snow or short-lived snow coverage during phase transition seasons, the presence of constant snow cover and ice for the rest of the year.

Acknowledgements

This study was carried out with the support of Project BG161PO003-1.2.04-0053-C0001 from Operational Programme “Development of the Competitiveness of the Bulgarian Economy 2007–2013, Project № DFNP -17-3 / 24.07.2017 - "Different approach for monitoring of flood and snow cover based on aerospace data in different spectral ranges" to the program for support of young scientists and PhD students at the Bulgarian Academy of Sciences and Programme “COPERNICUS” of European Union (European Space Agency).

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