# SAR POLARIMETRY IN REMOTE SENSING OF ARCTIC REGION

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## ABSTRACT

SAR polarimetry is a modern but mature technique in the Earth remote sensing, it is based on the measurements of the target scattering properties at different combinations of radar signal polarizations on transmit/receive. In our report we discuss an efficiency of polarimetric radar observations for thematic mapping of Yamal peninsula covers in Russian Arctic using L-band PALSAR-2 and X-band TanDEM-X SAR data acquired in different seasons of the years 2015-2016. To delineate surface dominating scattering mechanisms, we applied Pauli and Cloude-Pottier decompositions. Seasonal variations of bare soils and vegetation scattering properties as well as of industrial infrastructure were studied in both frequency bands. Arctic territories with presence of permafrost and lack of vegetation show lower variety of scattering mechanisms than areas in temperate latitudes. Anyways, polarimetric observations demonstrate high potential of radar remote sensing of Northern territories compared with single-channel measurements. L-band data show more opportunities for the Arctic monitoring than X-band data.

***Index Terms—*** SAR polarimetry, PALSAR, polarimetric decompositions, thematic analysis

## 1. INTRODUCTION

Growth of average air temperature in Arctic last decades has strong impact on the environment. Field trip observations revealed intensification of cryogenic processes including solifluction, thermal cirques formation, collapse of shorelines, etc. Geoecological risks and probabilities of significant economic damage due to the destructive effect of cryogenic processes are increasing. At the same time, intensive economic activity oriented to extraction of natural resources produces risks from ecological point of view. In the severe climate of the Arctic, the probability of emergency situations increases many times. There is strong need for the rapid detection, investigation and monitoring such an unwelcome events in the vast Arctic territories with complicated chances for access. At the same time there is need for permanent all-the-year monitoring of the industrial infrastructure state. Remote sensing techniques and instruments have potential for a monitoring of various environmental processes in various frequency bands (microwave, optical, etc.), including surface elevation changes because of thaw/freeze, landslides, avalanches, thermocarst lakes square dynamics, floods, erosion of shorelines [1].

SAR polarimetry is modern technique in Earth remote sensing, it is based on the measurements of the target scattering properties at different combinations of radar signal polarizations on transmit/receive [2,3]. Typically, the information content of polarimetric measurements is determined by inhomogeneity of scattering media. Arctic territories with presence of permafrost and lack of vegetation show smaller variety of scattering mechanisms than areas in temperate latitudes. Anyways, polarimetric observations may show remarkable potential of radar remote sensing of Northern territories and industrial infrastructure compared with single-channel measurements.

## 2. STUDY AREA AND DATA DESCRIPTION

Yamal peninsula is located on the North of Western Siberia, between 68°-73° N and 66°-73° E, it is known for the discovery and development of the largest gas and oil and gas fields in the world. Central and northern parts of the peninsula are covered with thin layer of sediments consisting of coarse fractions of sand, clay and peat soils forming good drainage structure. There are no outcrops of rocks. Average annual temperature is –7.5°C with positive trend +0.1 C/year during last 20 years. Steady snow cover exists from early October to mid-May. The snow cover thickness is about 30 cm, it reaches 2-3 m in local depressions. The permafrost thickness reaches 250 ÷ 400 m. Seasonal permafrost melting till 1 m depth takes place from early June till late September. Wetlands cover 60% of the territory. Terraced plains with height variations from 0 m in floodplain lowlands up to 40 meters on watersheds are typical for the study area. About 80% of the surface is occupied with slopes, so because of the ice layers melting beneath the upper soil covers during summer the thermal denudation processes in a form of landslides and solifluction are common.

In our report we discuss efficiency of polarimetric radar observations for thematic mapping of Yamal peninsula using L-band PALSAR-2 and X-band TanDEM-X SAR data acquired in 2015-2016 in different seasons of the year (ALOS-2: April 23 and August 25, TSX: August 09, 2015). SAR image frames borders (wider ALOS-2 frame and narrower TSX frame) are shown on Google map in Fig. 1. Bovanenkovo settlement location is marked with yellow pin.


Fig. 1. Bovanenkovo settlement and SAR frames borders on the Google map.

Typical permafrost test area near Bovanenkovo settlement selected for our study is specific for mostly single (surface) scattering because of the domination of open soils and water bodies.

## 4. DATA ANALYSIS RESULTS

The specific feature of the study area is the domination of the bare soils and water bodies, forming single scattering (SS). Vegetated territories with dipole or volume scattering (VS) and double-bounce (DB) are relatively rare. Of high importance is presence of industrial infrastructure elements. In Fig. 2 there is a set of 4 image fragments from AOLS-2 observation on August 25, 2016, representing scattering properties of the study area according to different mechanisms (single scattering, volume scattering and double bounce scattering). Image at HH polarization is presented for a comparison.

HH and SS images are very similar in appearance because of domination of surfaces with SS mechanism. The vegetated areas are poorly seen as well as gas pipes infrastructure. Vegetated areas are linked to water bodies and lowlands; they are better seen on HV and DB images especially because of the rejection the SS signal from surrounding bare soils. For the same reason industrial infrastructure, mostly concrete blocks along the gas pipes and industrial buildings are better seen on DB images.

An influence of seasonal variations of the surface radiophysical properties may be observed in Fig. 3. As it was shown in [4], soils freeze in cold seasons leads to a change of liquid water content and respective soil dielectric properties. The decrease of the dielectric constant value results in decrease of the backscatter. Polarimetric entropy (H) and mean scattering alpha angle ($\alpha$) parameters from Cloude-Pottier decomposition become lower, as it is typical for the less complex, surface-like scattering objects. The same is true for vegetation, where the dipole scattering mechanism is substituted by surface scattering [5,6].

In Fig. 3 there is a set of 4 image fragments from AOLS-2 observation on April 23, 2016, in a cold weather conditions, representing scattering properties of the study area according to different mechanisms like as in Fig. 2. One can see the decrease of the backscatter level on each image. HH and SS images here are similar again because of the domination of SS mechanism. The plots of HH and SS signals in Figs. 4 and 5 demonstrate that the backscatter variations in cold and warm seasons are similar for vegetation and bare soils. The same is true for HV and DB images. The backscatter of natural surfaces is 5-6 dBs lower in cold seasons. The discrimination of the vegetated and bare soils is better on HV and DB images obtained in cold seasons, though an influence of system noise floor at HV polarization may be noticeable in some cases.

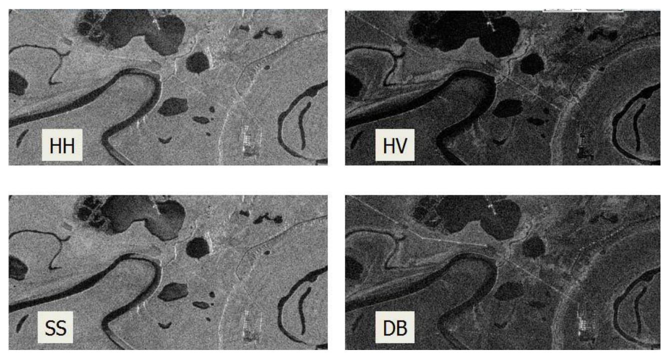


Fig. 2. Pauli decomposition of polarimetric L-band SAR image of industrial area on 25.08.2016.

As for the industrial infrastructure elements, their dielectric properties and, consequently, backscatter are stable all the year around. For that reason, the infrastructure is better seen on all the images from Fig. 3, but double-bounce scattering mechanism provides significantly better identification of gas exploration infrastructure in the presence of clutter signal from surrounding rough surfaces with dominating single scattering mechanism. H-$\alpha$ maps of Cloude-Pottier decomposition demonstrate the decrease of entropy and alpha angle values at negative temperatures. Dipole type of scattering practically disappears; vegetated surfaces are represented as surface scattering classes in a cold season, as it was mentioned in [5].

TSX SAR data acquired in August 09, 2015 were used to show the specificity of this frequency band for surface covers classification in permafrost environment. In Fig. 6 we demonstrate briefly the distinction of double bounce maps in L and X-bands. Industrial constructions look like bright patterns on the L-band image on the left; they are faintly visible on the right image (X-band). Vegetated areas along the extended lowland areas look as bright belts on the left; they are not discernible on the right image. The same is true for HV or volume scattering in Pauli decomposition. The dipole scattering is much more present on H-$\alpha$ maps in X-band sometimes because of low backscatter of territories, comparable with thermal noise of X-SAR system. We may state that surface scattering type is dominating one in both frequency bands. Dipole scattering mechanism, delineated in Cloude-Pottier decomposition, is more frequent both during winter and summer in the case of X-band data.

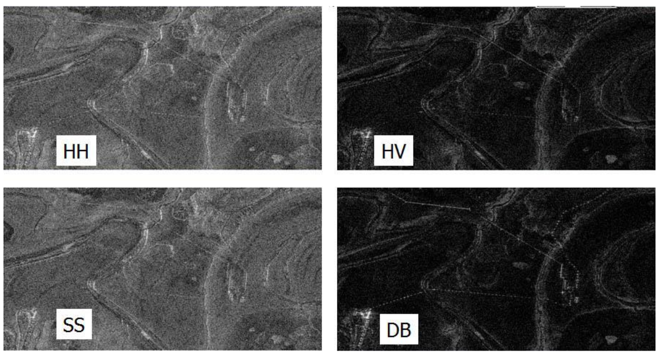


Fig. 3. Pauli decomposition of polarimetric L-band SAR image of industrial area on 23.04.2016.

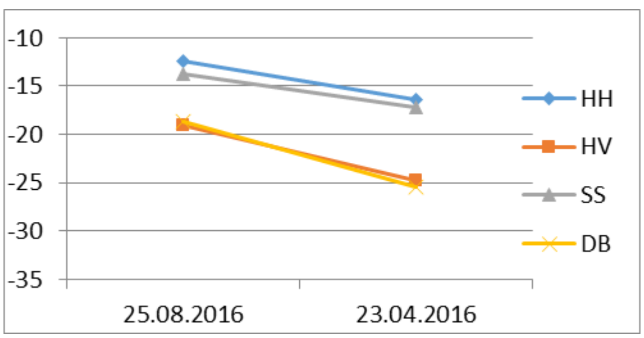


Fig. 4. Average normalized radar cross-section (in decibels) of vegetation.

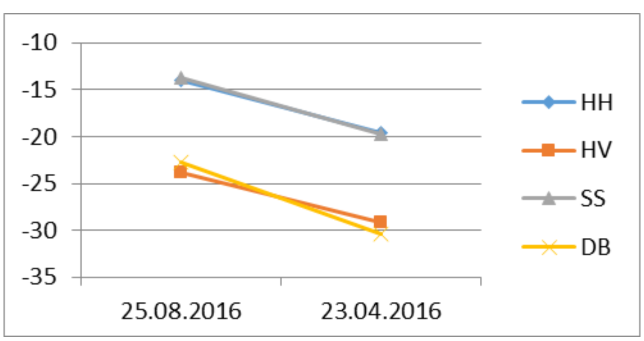


Fig. 5. Average normalized radar cross-section (in decibels) of bare soils (right).

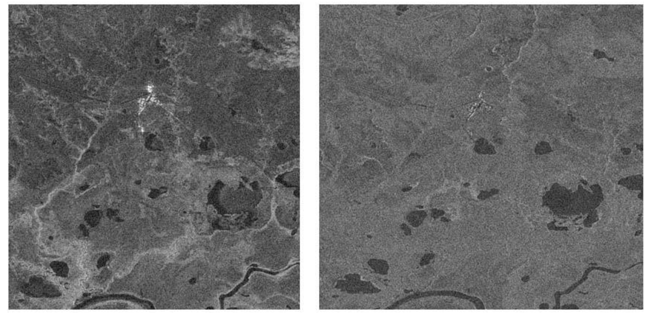

Fig. 6. ALOS-2 (left) and TSX (right) double-bounce images of Bovanenkovo settlement area.

Nowadays a high rate of cryogenic processes responsible for soils surfaces modification processes is a dangerous factor for Arctic territories exploration. There is a need of monitoring the landslides and thermal cirques processes as well as shorelines collapse. Small-scale vertical displacements of the scattering surfaces may be detected by differential radar interferometry technique provided the satellite repeat orbit interval is sufficiently short, but in the case of high rate of the surface deformation we have to put attention to variations of backscatter intensity and variations of polarimetric properties of scattering media [7].

In the case of cryogenic processes activation like as thermal cars or thermal basins the vertical walls of the topographic features shape may be responsible for the natural corner reflectors like backscatter. In the case of the landslide we may observe smoothing of the topography with respective decrease of double-bounce component of backscatter. Thus, the redistribution of the surface and double-bounce scattering components in the scattering matrix can serve as an indicator of the presence of cryogenic processes of the specific type [8,9].

The 3-D model of the test site with black arrows marking the location of thermal cirques and landslides at coastal lines is presented in Fig. 7 in RGB representation. Red channel is Tandem-X DEM, green – SAR intensity image from August 2015, blue – SAR intensity image from June 2015.

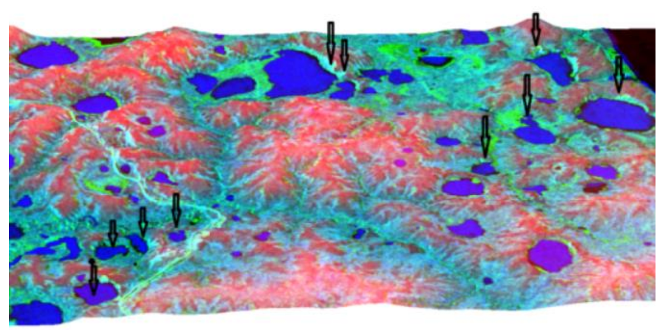

Fig. 7. 3-D model of the test site with thermal cirques and landslides.

Comparative analysis of variations of H, α and anisotropy (A) parameters shows that most distinction of the sites with thermal denudation processes from reference stable sites characterized by distinction in H and α parameters in midsummer time and after the snow/ice melting period. Parameter A does not show any seasonal variations in the each of the test sites.
The approach mentioned was applied in monitoring of the test sites with 3 types of cryogenic processes: 1) thermal cirques formed because of the rise of summertime air temperature in 2012-2015, 2) thermal cirques formed as a result of technogenic impact, and 3) coastal line retreat areas. In the first case most of the Cloude-Pottier decomposition parameters are helpful in detecting the cryogenic features except for A and combination H*α. In the second case most of parameters are useless, though there is slight chance for the combination of H and A. In third case most of parameters allow for the detection of the cryogenic features except for the A and H*α. The deviations of polarimetric parameters of the cryogenic features from background values are about 1-2 σ, so a combination of polarimetric parameters should be used to rise the detection reliability.
We may state that though polarimetric techniques in Arctic delineate significantly lower amount of scattering classes than in temperate latitudes, they are desirable because they provide the discrimination if vegetated and bare soils, and allow better observation of industrial infrastructure that single channel SAR systems. Winter observations are preferable because of higher contrast of stable double-bounce backscatter of industrial infrastructure compared with decreasing level of soils backscatter in cold season.
Also, L-band data show more opportunities for the monitoring of Arctic territories than X-band data.

## 5. CONCLUSION

Radar polarimetry provides extended opportunities in Arctic territories: maps of scattering mechanisms provide more reliable opportunity for mapping the Earth covers types and to monitor industrial infrastructure compared with single-channel SAR data. Winter observations with L-band SAR are preferable for the mapping of the industrial infrastructure, and summer observations are better for mapping vegetated and bare soils. L-band SAR data in applications discussed here are more informative than X-band SAR data.
In spite of significantly lower amount of scattering classes in Arctic than in temperate latitudes, parameters of polarimetric decompositions, their statistics, may be used to map location of small-scale surface cryogenic processes using multitemporal polarimetric SAR data.

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