Backscatter analysis of C-band radar signals using Sentinel-1 multitemporal data (test site near lake Baikal)

Pavel N. Dagurov[1], Aleksey V. Dmitriev[1], Tumen N. Chimitdorzhiev[1], Arcady K. Baltukhaev[1] and Irina I. Kirbizhekova[1]

[1]*Institute of Physical Materials Science, SB RAS, Ulan-Ude, Russia*

Abstract

The results of the analysis of multitemporal data of the Sentinel-1 radar for the test site near Lake Baikal are presented. The analysis of the seasonal dependences of backscattering from the soil is carried out. The connection between the signal level and the processes of freezing and thawing and temperature values has been established.

Keywords

Radar, Sentinel-1, backscatter, multitemporal data.

1. Introduction

Synthetic aperture satellite radars are an effective method of research and monitoring of earth covers, such as soil, forest, snow. The microwave range in comparison with the optical one has such a significant advantage as independence from cloudiness and time of day. An important advantage is also the fact that microwave radiation, in contrast to optical radiation, penetrates to a certain extent into the interior of the earth's cover. A common approach to the problems of determining (recovering) the parameters of the earth's cover by solving the inverse problem is to measure the backscattering coefficient, which characterizes the intensity of the radar signal.

An important type of backscatter radar data is the multi-temporal series of images obtained on different days. In the case of analyzing a series of images obtained by the same (or identical) instruments at different points in time, it becomes possible to trace, depending on the interval between surveys, various changes in natural cover, such as changes in soil moisture, freezing and thawing processes.

The magnitude of the backscattering of the SAR signal from the soil is determined by the dependence of its dielectric constant on the value of moisture and thawed or frozen state. The possibility of detecting soil moisture is due to the large contrast between the relative dielectric constant of dry soil, equal to 3–4, and water (∼80). Backscattering is also significantly affected by the roughness of the soil surface [1]. In the case of backscattering from the forest environment, the signal intensity depends on both the biophysical parameters of the forest and the properties

SDM-2021: All-Russian conference, August 24–27, 2021, Novosibirsk, Russia
dmitriev.aleksey@gmail.com (A. V. Dmitriev)

of the soil, and the contribution of various components is largely determined by the frequency of the radar signal.

Soil backscatter models developed over the past decades are generally classified into three groups; theoretical or physical, empirical and semi-empirical models.

Empirical models are based on experimental results and are generally only valid for the conditions at the time of the experiment. For example, it has been experimentally shown that the linear relationship between the backscatter coefficient and soil moisture is satisfied when soil moisture is in the range from about 10% to 35%, provided that the roughness does not change between successive radar measurements [2]. It has also been suggested that processing the rainy season image and the dry season reference image can eliminate the roughness effects [3]. This approach assumes that the roughness of the soil does not change between two dates, and is suitable for soils without vegetation. Empirical models are typically derived from specific datasets and implementation conditions (for example observation frequency, incidence angles, and surface roughness).

Semi-empirical backscattering models are based on a physical foundation, and then model or experimental data are used to simplify the theoretical backscattering model. They provide a relatively simple relationship between soil properties and backscattering and reflect, to a certain extent, the physics of scattering mechanisms. Thus, such models usually offer a good compromise between the complexity of theoretical models and the simplicity of empirical models [4]. Currently, the most widely used are two semi-empirical models developed by Oh et al. [5] and Dubois et al. [6]. Detailed information on their use is presented in [7]. The Oh model relates the backscatter coefficients of different polarizations to bulk soil moisture and surface roughness. An advantage of the Oh model is that only one surface parameter (namely, the root mean square roughness height) is required for its application. The model was applied for air and satellite SAR measurements [4, 8]. A number of researchers have used the Dubois model, obtaining both satisfactory results (for example, [4, 11]), and not so satisfactory results [9].

The use of theoretical (physical) models makes it possible to simulate radio wave scattering using soil parameters (dielectric constant and surface roughness) by taking into account the interaction between microwave radiation and soil. They are based on the equations of electrodynamics. The disadvantage of such models is that they require a large number of input parameters, which makes their application rather complicated [1]. Currently, the standard theoretical models used in backscattering theory include the Kirchhoff approximation, the small perturbation method [10], and the integral equation method [11].

Let us dwell on the problem of remote sensing of snow cover on the ground using SAR. In [12], it is noted that due to the vastness and inaccessibility of many regions covered with snow and ice, space remote sensing is the most popular tool for studying snow and ice. As in the case of remote sensing of soil moisture, currently the main approach to sensing snow using SAR is to measure and analyze the intensity of the scattered signal. The total power of backscattering from the snow cover on the soil is due to the contribution of various mechanisms, which can be roughly divided into two categories: surface scattering and volume scattering. In [13], the potential of the C-band SAR data for determining the water equivalent of snow was estimated. To estimate the water equivalent, a model has been developed that relates the scattering coefficient to the parameters of snow cover and underlying soil and is based on the ratio of scatter from a field covered with snow to scatter from a field without snow. The results showed that volume scattering from dry snow cover less than 20 cm in height was not detectable.

In this work, the time dependences of the backscattering of C-band microwaves at the test site near Lake Baikal are analyzed based on the multi-time series of images of the Sentinel-1 satellite radar. The results of studying the processes of soil melting/freezing and the effect of snow cover based on the analysis of seasonal variations in backscattering are presented. For comparison, the seasonal dependences of forest backscattering are shown.

2. Study area and dataset

Investigations were carried out at a test site located near Lake Baikal. In Figure 1 shows a pseudo-color image of a test area located near Lake Baikal. The image was formed from autumn images (R), summer images (G), and winter images (B). In the image, plots 1, 2, 3 in the field (pasture) and plots 4, 5. 6 in the forest adjacent to the field were highlighted.

The field is relatively flat with a size equal to 2×1 km covered by sparse grass. The relief height differences are less than 5 m. The forest mainly consists of conifers with a tree height of about 20 m with a fullness of 0.5–0.8.

For backscatter analysis, images of the Sentinel-1 C-band synthetic aperture satellite radar (5.55 cm wavelength) were used. A great advantage of the images obtained by this satellite is a rather small time baseline, which is 12 days for one satellite, and free access to data, which makes it possible to form long time series. When using two satellites (Sentinel-1A and Sentinel-1B), the time interval between surveys is 6 days, however, in the territory of Buryatia, when using data obtained in one orbit, only a 12-day interval is available. For the analysis, we used images in

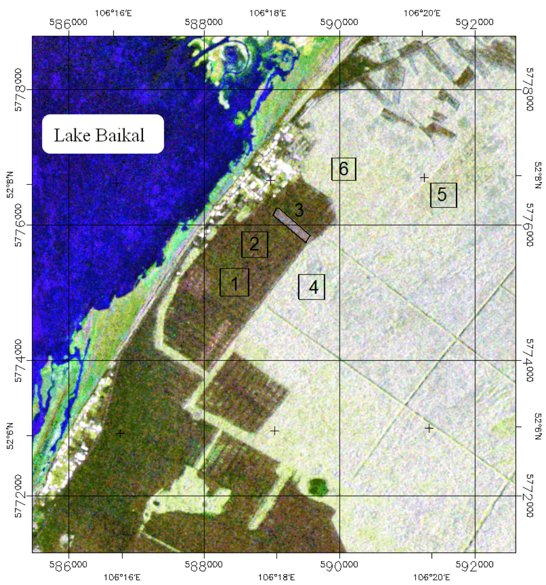

Figure 1: Pseudo-color image of the test area (1, 2, 3 — field; 4, 5, 6 — forest plots).

Table 1
Dates of Sentinel-1B radar imagery (descending orbits).

No.	Date	rel./abs. No. orbit	No.	Date	rel./abs. No. orbit
1	19.07.2018	135/011886	23	21.04.2019	135/015911
2	31.07.2018	135/012061	24	03.05.2019	135/016086
3	12.08.2018	135/012236	25	15.05.2019	135/016261
4	24.08.2018	135/012411	26	27.05.2019	135/016436
5	05.09.2018	135/012586	27	08.06.2019	135/016611
6	17.09.2018	135/012761	28	02.07.2019	135/016961
7	29.09.2018	135/012936	29	14.07.2019	135/017136
8	11.10.2018	135/013111	30	19.07.2019	33/017209
9	23.10.2018	135/013286	31	31.07.2019	33/017384
10	16.11.2018	135/013636	32	12.08.2019	33/017559
11	28.11.2018	135/013811	33	24.08.2019	33/017734
12	10.12.2018	135/013986	34	05.09.2019	33/017909
13	22.12.2018	135/014161	35	17.09.2019	33/018084
14	03.01.2019	135/014336	36	29.09.2019	33/018259
15	15.01.2019	135/014511	37	11.10.2019	33/018434
16	27.01.2019	135/014686	38	23.10.2019	33/018609
17	08.02.2019	135/014861	39	04.11.2019	33/018784
18	20.02.2019	135/015036	40	16.11.2019	33/018959
19	04.03.2019	135/015211	41	28.11.2019	33/019134
20	16.03.2019	135/015386	42	10.12.2019	33/019309
21	28.03.2019	135/015561	43	22.12.2019	33/019484
22	09.04.2019	135/015736			

the IW mode with a resolution of 10×10 m in the polarization modes VV and VH, i.e., radiation on vertical polarization, and reception on the main vertical polarization and on the horizontal cross-component. For the analysis, 43 images were used, obtained in the period from July 19, 2018 to December 22, 2019. Note that the orbit over the study area was changed on July 19, 2019. The orbit number has changed from 135 to 33, and the radar angle of view from 33.6° to 38°. Table 1 shows the imagine dates of the Sentinel-1B over the study area.

Images were processed using ESA SNAP and ENVI software.

The climatic conditions of the study area are determined by its location in Buryatia (Eastern Siberia, Russia), which features a sharp continental climate. In the cold season, the Siberian (Asian) anticyclone occurs. Therefore, a large number of sunny days and low air temperatures mark the winters in Buryatia. Winters feature negative temperatures ranging to -35 °C with no thaws, and the snow is dry until the end of the thawing period (March–April). In February, the soil freezes to a depth of more than 2 m.

3. Results and discussion

Figure 2 shows the time series of intensities averaged over sections 1–6. From the analysis of the given dependences, it follows that the values of backscattering for plots 1, 2 and 3 in the field

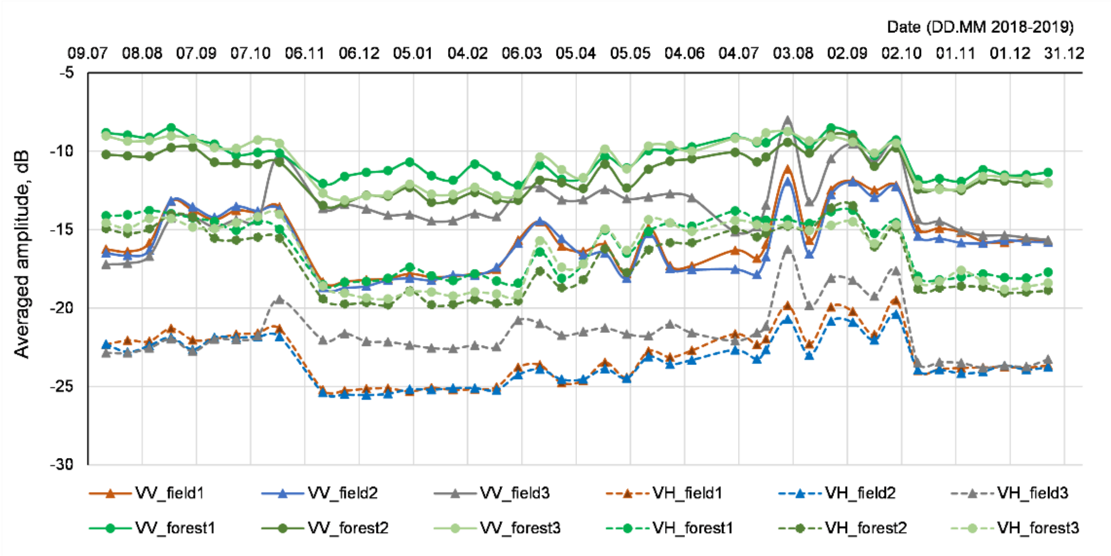

Figure 2: Time series of averaged backscattering amplitudes of VV and VH for field and forest.

before the moment of plowing are close to each other until the moment of plowing section 3. The signal levels on the main polarization and cross-component have increased by 3–5 dB after plowing in autumn 2018. Note the pronounced seasonal dependence of the signal behavior due to freezing and thawing of the soil. When freezing, the dielectric constant of the soil decreases slightly depending on the temperature. Therefore, the signal level changes little during the winter months. In the summer months, there are noticeable fluctuations in the intensity of the radar signal, caused by changes in soil moisture due to rains and the subsequent drying of the soil.

For comparison with the time series of signal intensities in Figure 3 shows the dependences of the air temperature at a height of 2 m on the number (date) of the day, obtained at 5 o'clock and 14 o'clock local time during the periods of freezing and thawing of the soil. Data obtained from the site https://www.ventusky.com. Comparison of the time course of backscattering and air temperature shows an obvious correlation between the moments of soil freezing and the transition of temperature from positive values to negative values. When the soil thaws, such a clear correlation is not observed. Let us consider the issue of the correlation between the temperature and the backscattering amplitude in more detail. In 2018, from the analysis of the dependencies in Figure 2 it follows that the level of the backscattered signal from the areas in the field on November 16, 2018 (Table 1) decreased compared to the signal level on October 23, 2018 by 5 dB at the main polarization and by 4 dB at the cross-polarization. Unfortunately, the data for April 11, 2018 turned out to be unavailable on the European Space Agency portal. On plowed area 3, these values were 2.5–3 dB. It can be assumed that this is due to the incomplete plowing of plot 3 as of November 16, 2018. Analysis of temperatures in Figure 3, a shows that on October 23, 2018 and in the previous period, the air temperature was positive, and on November 4, 2018 (starting from November 1, 2018, it was below zero and the topsoil had time to freeze).

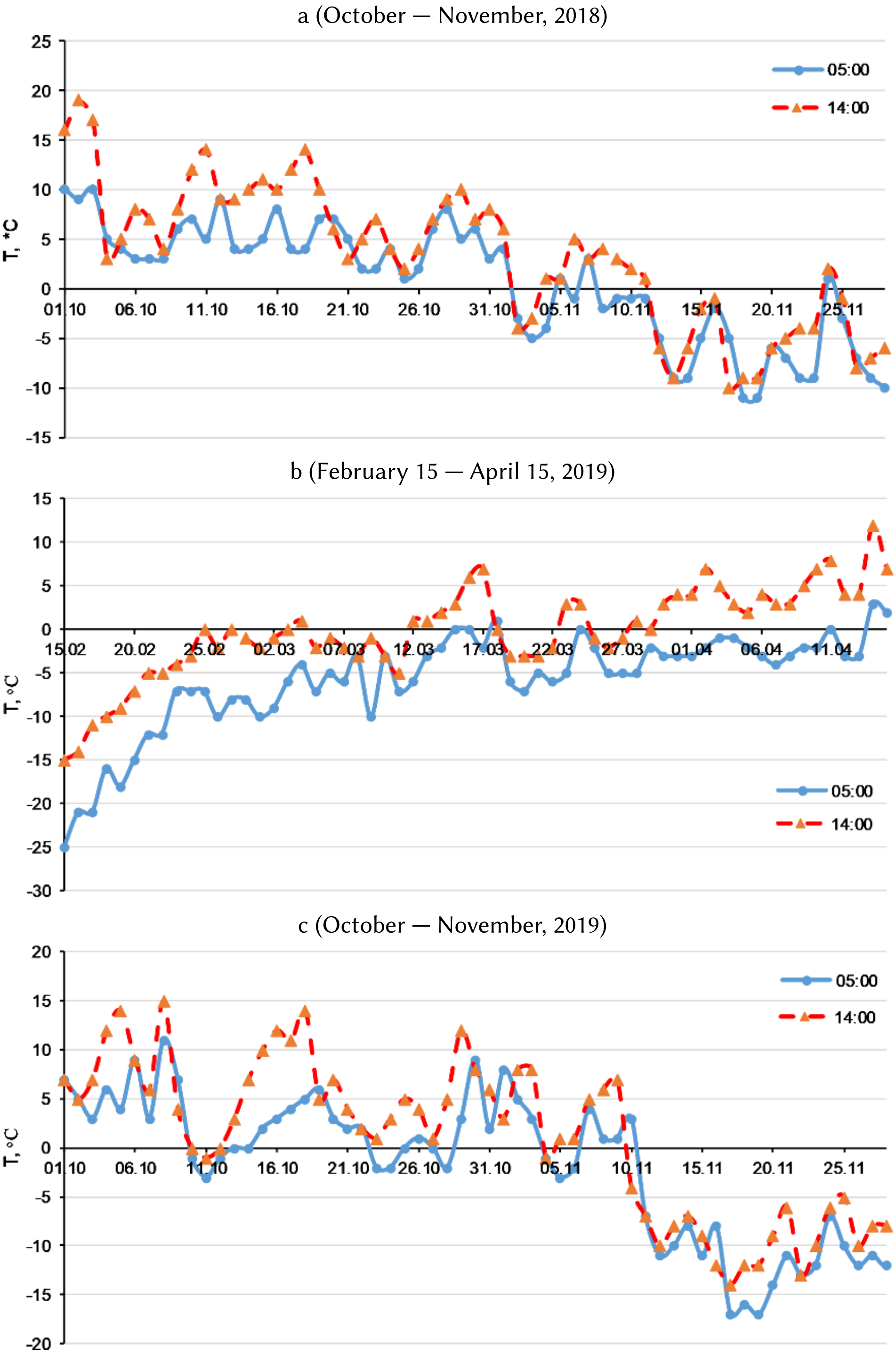

Figure 3: Air temperature during periods of freezing/thawing of the soil: a — freezing, 2018; b — thawing, 2019; c — freezing, 2019.

The process of thawing the soil is more difficult because it is accompanied by melting snow. Figure 2 shows that according to the data for February 20, 2019 and March 16, 2019, the signal level increased by 4 dB, and then decreased due to soil drying after snowmelt and cyclic freezing of the upper soil layer, which is confirmed by the data in Figure 3, b.

The process of soil freezing in 2019, in a similar way compared to 2018, affected the amplitude of the backscattered signal from the soil, causing it to decrease by 3–4 dB at the main polarization and by 4–5 dB at the cross-component. However, the freezing process in 2019 began much earlier than in 2018. According to Table 1 of satellite flights, the signal level dropped already on October 11, 2019, and from Figure 3c it follows that on this day the temperature was below zero. It is interesting to note that with a predominance of positive temperatures up to November 10, it was on the days of satellite flights that the temperature was negative.

Note that the behavior of the signal scattered by the forest significantly correlates with the dependences obtained for the soil. A pronounced seasonal variation is also observed.

From the presented dependences it follows that the snow cover does not affect the amplitude of the radar signal. This is evidenced by the steady decrease in the signal amplitude in October-November when the soil freezes, while the snow cover usually forms in December. So, for example, snow at the end of 2019 began to fall on December 1 and went for 3 days, forming a snow cover 20 cm thick. However, this dry snow cover did not affect the level of the radar signal.

4. Conclusion

The paper analyzes the time series of the Sentinel-1 radar backscattering at the test site near Lake Baikal. It was found that backscattering in the test area has a pronounced seasonal dependence. It is shown that as a result of the processes of freezing and thawing of the soil, the signal level at the main polarization and cross-polarization changes within 3–5 dB. A comparison of the dependences of changes in the signal level with the values of air temperature was carried out and their relationship was established. A significant correlation was found between changes in backscattering from soil and forest. It is shown that dry snow cover with a height of 20 cm does not affect the backscatter in the C-band.

Acknowledgments

The authors would like to thank European Space Agency (ESA) for Sentinel-1 data. The research was carried out within the state assignment of Ministry of Science and Higher Education of the Russian Federation.

References

[1] Moran M.S., Peters-Lidard C.D., Watts J.M., McElroy S. Estimating soil moisture at the watershed scale with satellite-based radar and land surface models // Canad. J. Remote Sens. 2004. Vol. 30. No. 5. P. 805–824.

[2] Zribi M., Baghdadi N., Holah N., Fafin O. New methodology for soil surface moisture estimation and its application to ENVISAT-ASAR multi-incidence data inversion // Remote Sens. Environ. 2005. Vol. 96. P. 485–496.

[3] Baghdadi N., Camus P., Beaugendre N., Issa O.M., Zribi M., Desprats J.F., Rajot J.L., Abdallah C., Sannier C. Estimating surface soil moisture from TerraSARX data over two small catchments in the Sahelian part of Western Niger // Remote Sens. 2011. Vol. 3. No. 6. P. 1266–1283.

[4] Panciera R., Tanase M.A., Lowell K., Walker J.P. Evaluation of IEM, Dubois, and Oh radar backscatter models using airborne L-band SAR // IEEE Trans. Geosci. Remote Sens. 2014. Vol. 52. No. 8. P. 4966–4979.

[5] Oh Y., Sarabandi K., Ulaby F.T. An empirical model and an inversion technique for radar scattering from bare soil surfaces // IEEE Trans. Geosci. Remote Sens. 1992. Vol. 30. P. 370–381.

[6] Dubois P.C., van Zyl J., Engman T. Measuring soil moisture with imaging radars // IEEE Trans. Geosci. Remote Sens. 1995. Vol. 33. P. 915–926.

[7] Barrett B., Dwyer E., Whelan P. Soil moisture retrieval from active spaceborne microwave observations: An evaluation of current techniques // Remote Sens. 2009. Vol. 1. P. 210–242.

[8] Koyama C.N., Sato M. Soil moisture and biomass retrieval using ALOS/PALSAR data // Synthetic Aperture Radar (APSAR). 2013. Asia-Pacific Conference. P. 49–52.

[9] Alvarez-Mozos J., Gonzalez-Audicana M., Casali J. Evaluation of empirical and semi-empirical backscattering models for surface soil moisture estimation // Canad. J. Remote Sens. 2007. Vol. 33. No. 3. P. 176–188.

[10] Ulaby F.T., Moore R.K., Fung A.K. Microwave remote sensing: Active and passive, Vol. III. From theory to application. Dedham, MA: Artech House, 1986

[11] Fung A.K., Li Z., Chen K.S. Backscattering from a randomly rough dielectric surface // IEEE Trans. Geosci. Remote Sens. 1992. Vol. 30. P. 356–369.

[12] Rees W.G. Remote sensing of snow and ice. CRC Press. Taylor & Francis Group, 2006.

[13] Bernier M., Fortin J.-P. The potential of times series of C-Band SAR data to monitor dry and shallow snow cover // IEEE Trans. Geosci. Remote Sens. 1998. Vol. 36. No. 1. P. 226–243.