Time-Series SAR Observations of Chukotka Sub-Arctic Lakes and Forest-Tundra Fire Scars

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Abstract - Studies of seasonal changes of ERS-2 SAR backscatter from sub-Arctic lakes and forest-tundra fire scars in Chukotka, Russia, have been carried out for the four seasons of the period between 2000 and 2004. Correlation analyses of time series of radar backscatter from the set of 13 lakes within Anadyr Lowland distinguished 3 groups of lakes. Time-series studies of SAR observations of the fire risk areas in the vicinity of Vaegi Village before and after fires give an assessment of forest-tundra damage that can be used in land use inventories. The snow masking effect of tundra fire scars and wet snow case were also demonstrated.

Keywords: SAR, Chukotka, lakes, fire scars, snow masking effect

1. INTRODUCTION

Remote sensing is a particularly valuable observational tool in the Russian Far East and Siberia due to the lack of existing ground-based measurements across the vast land area and because of the rapid climate changes taking place in these Arctic regions. SAR is an especially valuable technology in this region because it provides data regardless of weather or light conditions. Studies of seasonal changes in SAR backscatter from certain land features in two locations (Anadyr River Research Area - ARRA and Vaegi Village Research Area - VVRA) in Chukotka, Russia, have been carried out for the four seasons of the period between the years 2000 to 2004, fig.1 These studies are being conducted as part of the NASA project "Reindeer Mapper" to increase capabilities for monitoring, risk mapping, and surveillance of parameters critical to the characterization of reindeer pasture quality and migratory routes in the Russian Arctic. These studies demonstrate the use of SAR for providing useful information about some of these key environmental parameters.

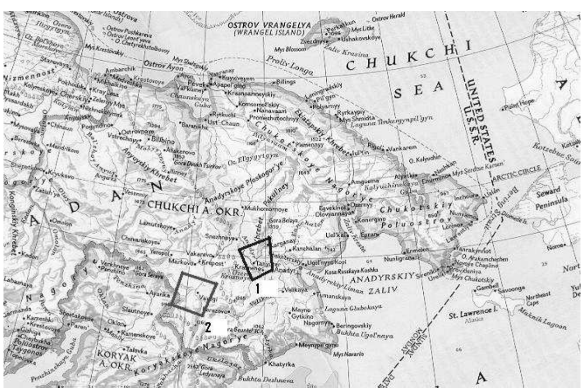

Figure 1. Locations of research areas within Chukotka Autonomous Okrug ; 1-Anadyr River Research Area 2- Vaegi Village Research Area

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** This work is supported by the NASA Land-Cover Land-Use Change Program and NASA's Radar Research Program (NASA #51-621-21-01-20). Synthetic Aperture Radar data are provided by the European Space Agency and Alaska Satellite Facility.

2. OBSERVATION OF CHUKOTKA SUB-ARCTIC LAKES

According to Morris et al., (1995) sub-Arctic lakes provide promising sites for long term monitoring and the detection of changes related to global warming and their effects on the polar regions. The interpretation of the Arctic and sub-Arctic tundra lake SAR signatures in Canada and Alaska has been widely discussed in the literature by (Sellmann et al., 1975); (Elachi et al., 1976); (Hall et al., 1994); (Weeks et al., 1997); (Duguay et al., 2002); (Yoshikawa et al., 2003) and others. The radar brightness of the lakes in winter varies significantly. Some lakes look like bright spots; others, as black spots on the same SAR image. The effect can be caused by the different depths to which each lake has frozen. The so-called "shallow" lakes, frozen to the bottom, reflect SAR irradiance from the bottom; the "deep" lakes, unfrozen to the bottom, have an ice-water interface that reflects radar irradiance specularly. In the first case, a part of radar energy scattered diffusely from lake bottom goes back to the radar. Its strength depends on the difference of dielectric permittivity between ice and lake sediments. The frozen sediments absorb the energy; the wet sediments can give a higher radar return. In the case of pure ice, because of attenuation of the ice layer and snow cover, the deeper the frozen lake bottom is, the less the backscatter is. An exception to this rule can occur if there are bubbles imbedded in the ice layer. The bubbles provide an additional contribution to the backscatter. With specular reflection, practically all of the energy spreads out of a radar. The snow layer over the ice lake surface also contributes some backscatter due to snow volume scattering. This is a significant factor for polar regions, particularly during warm winters due to climate warming which is accompanied by increased precipitation. Thus, while the interpretation of winter lake SAR signatures is a complex task, it is clear that the signatures can be correlated with regional and seasonal environmental parameters.

Therefore,, the study of SAR backscatter from sub-Arctic lakes is an interesting and promising technology for the environmental remote sensing in high latitudes.
For Chukotka, SAR sounding was done for the deep lake, El'gygytgyn (the north of the region) by (Nolan et al., 2003).
This paper presents some preliminary results of lakes' radar backscatter coefficient (RBC) studies for a set of lakes within the ARRA research areas, fig.2.The data processing was performed by ENVI v3.4 software and includes radiometric calibration. The primary ERS-2 SAR (C band, VV- polarization, 20^0-26^0 incidence angle) low-resolution images were received from Alaska Satellite Facility (Fairbanks). To keep local incidence angles approximately the same, SAR data granules were selected with the frame center coordinates varying from each other no more than

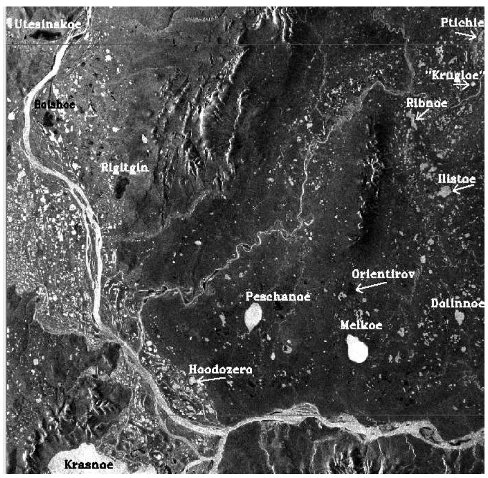

Figure 2. Location of lakes within ARRA
ERS-2 SAR low resolution image. January 14, 2002.
Area sizes (HxW): ~110x100 km.
Upper Left Corner: $65^0$19'12" N, $173^0$17'24" E
Upper Right Corner: $65^0$34'12" N, $175^0$20'24" E
Lower Left Corner: $64^0$22'48" N, $173^0$58'12" E
Lower Right Corner: $64^0$37'48" N, $175^0$57'36" E

$\pm 0.01^0$. Data from the different years within 2000-2004 were used to create a continuous series of raw RBC values through a 12 months annual cycle. These data were compiled in a list together with weather data from local weather stations "Tanurer" (#25561) and "Anadyr" (#25563) and presented in table A.

Table A. List of SAR dates and weather data of Anadyr Lowland ("Russian's Weather" Server)

Date	Average temperature, ^{0}C	Snow depth, cm
01/14/2002	-37.4	23
02/23/2004	-27.8	20
03/25/2002	-6.3	21
03/29/2004	-22.7	22
04/24/2000	-15.2	19
05/03/2004	-6.7	18
06/03/2002	5.3	0
06/18/2001	16.0	0
07/12/2004	18.5	0
07/28/2003	12.0	0
08/16/2004	10.2	0
09/11/2000	4.7	0
09/20/2004	7.5	0
10/06/2003	-7.8	0
11/05/2001	-8.4	24
12/15/2003	-14.7	31

The time series study of lakes' RBC has two common features:
1. The majority of the lakes have a marked decrease in backscatter in October due to specular reflection from the water beneath a thin layer of ice;
2. The summer backscatter decrease in June/July is connected with specular reflection from open water in calm weather (local wind speed is low).
The correlation between the pairs of lakes' RBC time series indicates three groups of the lakes: Group I: Utesinskoe, Bolshoe, Rigitgin. Correlation between these is weak (0.1<R<0.5) and poor (R<0.1) with other lakes; Group II: Peschanoe, Melkoe, Orientirov, Dolinnoe, Ilistoe, Ribnoe, Krugloe, Krasnoe. Correlation between these is high (R>0.8); Group III: Ptichie, Hoodozero. Correlation between these is high (R~0.95) but weak (0.2<R<0.6) with other lakes. The depth of the three lakes of group II is: Peschanoe – 3 m, Melkoe – 1.9 m, Krasnoe – 0.6 m (Lubomirov A.S. *Lakes of Chukotka Criolit Zone*, Yakutsk: USSR Acad. Sci. Publ. 1990.-1976. (Courtesy of Prof. S. Ryanzhin (Institute of Limnology of RAS).
Therefore, it can be proposed that the lakes of group II are shallow (h~1 – 3 m) and lakes of groups I and III differ in depth from the lakes of group II. Time series studies of radar backscatter from typical lakes of all groups are shown on fig.3. (Y-error bars are have been omitted for a clearer view of the data).

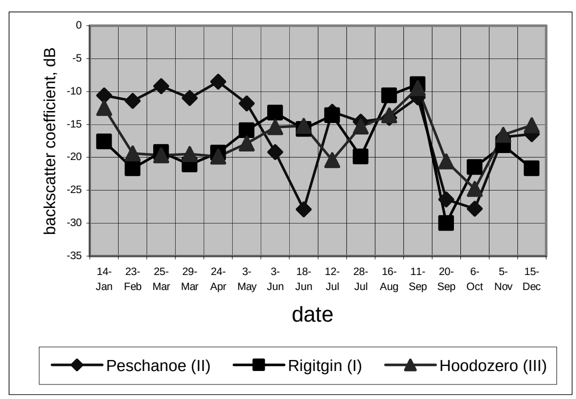

Figure 3. Radar backscatter versus months for typical Anadyr Lowland lakes

The most obvious difference between the lakes is their backscatter behavior in winter. The mean backscatter coefficient of group II is higher than that of groups I and III by ~ 10 dB. Group III is closer to group I in general with some deviations in early winter and summer. Also the winter-spring transition of Peschanoe lake's backscatter (group II) indicates a negative slope in the period between 24 April and 18 June. These features should be verified by further studies including in-situ measurements of lakes' depth, snow cover and ice properties.

3. FIRE SCAR DETECTION AND MONITORING

A significant number of forest-tundra fires occur in Chukotka annually. The fire damage to the reindeer pastures make it necessary to change the migration routes of reindeer herds. Therefore, creating a fire scar inventory is an important task of the local authorities. The most common technique used is aerial reconnaissance, but this method is very expensive and not very accurate (Mironenko, 2000). One of the most severe fires occurred in the vicinity of Vaegi village of Anadyr district in 2002 and 2003. The result of SAR monitoring of this area is shown on fig.4.

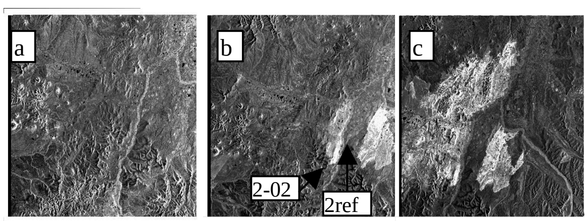

Figure 4. ERS-2 low resolution SAR images of the same sub-Arctic tundra area in the vicinity of Vaegi village of Chukotka;

a- before fires (August 8, 2002);
b- after fire1 (September 6, 2002);
c- after fire2 (September 7, 2003).

Test sites are shown by arrows. Image size: ~ 110 x 100 km
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The fire scars are very clearly delineated by SAR and can be mapped for fire scar inventories in conjunction with MODIS Rapid Response System (Justice et al., 2002).
During the winter, the contrast between a fire scar and the nearby undamaged area is smoothed (See fig.5).

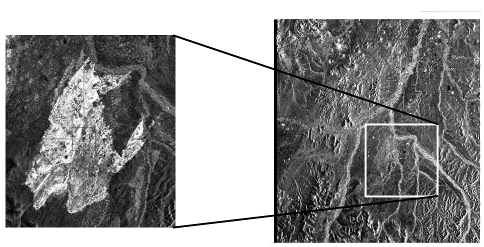

Figure 5. Vaegi fire scars in the Fall (left image, September 7, 2003) and in winter (right image, February 29, 2004). SAR low resolution image. Shows good example of the masking effect of snow cover. Snow depth =72 cm. ©ESA (2004).
The smoothing is caused by the snow masking effect (Ulaby et al., 1984). The calculated contrast (difference in dB between corresponding backscatter coefficients) for selected test sites within fire scar 2002 and the relevant weather data from weather station "Markovo" ("Russia's Weather" Server) are presented in Table B. Unfortunately, snow depth data are not available for 2004/2005 winter.

Table B. Radar contrast between 2-02 fire scar and 2ref site

Date	Contrast, dB	Snow depth, cm	Temperature, °C
09/06/02	6.02	0	9.2
10/11/02	4.4	12	-0.2
11/15/02	3.6	24	-23.4
12/01/02	2.8	24	-27.6
01/05/03	2.6	38	-31.5
01/24/03	3.2	54	-14.5
02/09/03	2.9	53	-36.9
02/28/03	3	59	-16.3
03/16/03	2.8	57	-23.6
04/20/03	2.8	61	-13.3
05/25/03	4	2	4.4
06/29/03	3.7	0	10.3
08/03/03	5.5	0	17.6
09/07/03	6.4	0	9.2
09/26/03	7.3	0	5.8
10/12/03	5.5	3	-9.8
10/31/03	3.8	18	-7.7
11/16/03	3	22	-23.2
12/05/03	2	35	-21
12/21/03	2.2	48	-33
01/09/04	2.6	70	-31.9
01/25/04	2.3	28	-6.2
02/29/04	2.5	72	-17.6
04/04/04	1.5	70	-20.7
04/23/04	1.4	72	-14
05/09/04	3	12	-0.5
05/28/04	2.2	0	7
06/13/04	5.3	0	16.1
07/18/04	3	0	16
08/06/04	5.4	0	13.8
08/22/04	6.2	0	11.8
09/10/04	6.5	0	10.9
09/26/04	5.4	0	-0.2
10/15/04	3.7		0.1
10/31/04	2		-23.4
11/19/04	2.5		-21.2
12/05/04	2.4		-13.9

It follows from this table that upon a decrease in the temperature to negative value and without significant snow cover (10/11/02 and 10/12/03), the contrast decreased by ~ 2 db in comparison with its maximum value 6-7 dB in summer (09/07/03, 09/26/03 and 08/22/04, 09/10/04). Due to snow cover the contrast reached values up to ~ 3 dB at snow depth ~ 60 cm and ~ 2 dB at snow depth ~ 70 cm. A numeric illustration of snow masking effect previously shown on fig.5 is presented in fig.6.
It should be mentioned also in the context of SAR backscatter sensitivity from fire scar to snow cover property, that on May 9, 2004 the backscatter coefficient from fire scars decreased on 8-12 dB due to wet snow conditions, (See fig.7, table C).

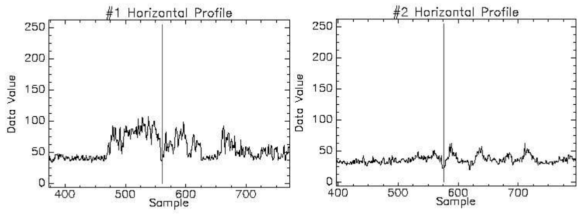

Figure 6. Horizontal profiles of radar brightness values through the same point within the fire scar of fig.5 (left image). #1 – without snow, #2- with snow depth =72 cm.

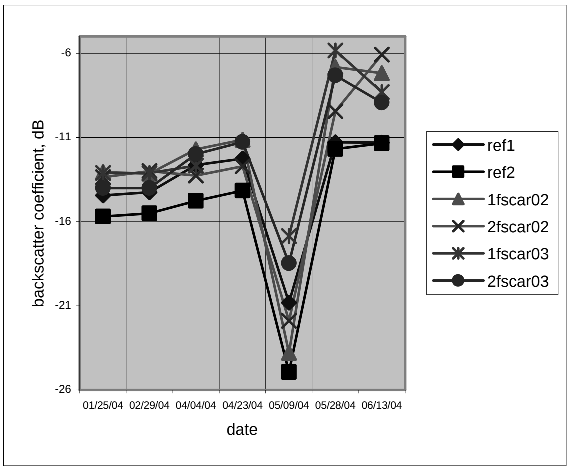

Figure 7. Decrease of backscatter coefficient due to snow melting for several references sites and fire scars within VVRA

Table C. Weather data of "Markovo" w/s ("Russia's Weather" Server)

Date	Temperature, ^{0}C	Snow depth, cm	Event
05/06/04	+1.5	16	Snow/rain
05/07/04	+1.8	67	Rain/snow
05/08/04	+0.8	13	Snow
05/09/04	-0.5	12	Snow

5. SUMMARY

The results of SAR monitoring of a set of sub-Arctic lakes within the Anadyr Lowland indicate 3 groups of lakes which are differentiated through time series studies of radar backscatter. The most numerous group is that of shallow lakes with depths 1-3 m.

A short history of forest–tundra fires in the vicinity of Vaegi Village is shown. The SAR images show a clear configuration of fire scars which, in turn, illustrate how SAR can be used for land use inventory purposes, such as characterization of reindeer pastures quality and migration routes.

Another result of this research on the use of SAR for fire scar monitoring demonstrates a clear snow masking effect that can be applied to dry snow parameter assessment. Detection of wet snow conditions was also shown as part of this study. Therefore, it may be concluded that fire scar monitoring is useful not only for land use inventories, but also for snow parameter assessment.

These different applications of SAR clearly demonstrate the usefulness of SAR as a valuable tool for monitoring land cover and land use changes of remote areas in the Arctic for characterization of reindeer pasture quality and migratory routes.

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