Space Technologies for Enhancing the Resilience and Sustainability of Indigenous Reindeer Husbandry in the Russian Arctic

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Abstract - In response to the major changes taking place across the Arctic - climatic, environmental, economic, social, industrial - there is an increasing need for improved land cover/land use change information, especially remotely sensed data, by indigenous reindeer herders on the characterization of pasture quality and migratory routes, such as vegetation distribution, snow cover, infrastructure development, and pasture damages due to fires. This paper describes some of the remote sensing capabilities useful for reindeer husbandry and preliminary results of the first year of a project, "Reindeer Mapper", a remote sensing and GIS-based system to bring together space technologies with indigenous knowledge for improved mapping of parameters critical to sustainable reindeer husbandry.

Keywords: remote sensing, reindeer, Russia, Arctic, indigenous, SAR, sustainability.

1. INTRODUCTION

It is well known that reindeer husbandry is very sensitive to changes in the environment, and in Northern Russia, climate change with warmer temperatures plus land cover/land use changes, industrial development, and dramatic economic problems have combined to create a serious threat in recent years for reindeer husbandry (Jernsletten, 2002). Problems created by environmental and climate changes for reindeer herds include changes in precipitation, ice state, permafrost, and snow, increased insect harassment and vulnerability to predators and pollution (Anisimov and Fitzharris, 2001; Walsh et al 1992; Brotton and Wall, 1997; Gunn and Skogland, 1997). In addition, industrial development (e.g., pipelines and oil and gas infrastructure) is increasing on reindeer pastures and migratory routes in Northern Russia, often blocking pathways to traditional pasturelands (Vistnes et al., 2002).

Remotely-sensed data and observations are providing increased capabilities for monitoring, risk mapping, and surveillance of parameters critical to the characterization of pasture quality and migratory routes, such as vegetation distribution, snow cover, infrastructure development, and pasture damages due to fires.

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This paper describes some of the remote sensing capabilities applicable to reindeer husbandry and preliminary results of the first year of a project, "Reindeer Mapper", which is a remote sensing and GIS-based system to bring together space technologies, ground-based measurements, and indigenous knowledge for sustainable reindeer husbandry. The purpose of Reindeer Mapper is to try to reduce the threats to reindeer husbandry from changes in the climate, environment and human-induced activities and improve community resilience and ability to adapt to these changes by providing usable, timely knowledge from detailed analyses of satellite data combined with traditional, local and other data and information.

2. SPACE TECHNOLOGIES APPLICABLE TO REINDEER HUSBANDRY

The definition of data and technology requirements applicable to reindeer husbandry in Russia is based upon the major issues facing reindeer herder communities. Two primary issues creating a critical situation in indigenous reindeer husbandry in Northern Russia are the drastic changes in the environment and the economy. It is, of course, the environmental changes that may be directly addressed by space-based technologies. Based upon discussions among Reindeer Mapper team members from the reindeer herder community, including discussions and publications such as the Yakutsk Declaration from the Third World Reindeer Herders' Congress in March 2005, a preliminary list of the highest priority environmental measurements has been created. These requirements constitute the primary elements of pasture quality, the most important overall set of parameters for reindeer herders. A summary of these data requirements is listed in Box 1.

Information for many of the environmental variables listed in Box 1 for characterization of pasture quality can be derived from data collected in several spatial and temporal scales by a number of the space-borne remote sensing instruments in orbit today. For example, ecological characterization of the pasturelands and migration routes, including human infrastructure, can be accomplished through the use of the extensive suite of land cover and land use change optical space sensors. In fact, there are a number of remote sensing studies, which have been carried out to assess various aspects of the state of reindeer pastures using some of these technologies. A brief summary of the use of these technologies for reindeer husbandry is presented in the following section.

High Priority Remote Sensing Observations and Data for Reindeer Husbandry

- Ecological characterization of seasonal pasturelands and migration routes and assessment of their suitability as pasture
- Depth and characteristics of snow cover of pasturelands and migration routes
- Condition of ice on rivers, lakes and other water bodies in migratory routes
- Assessment of anthropogenic impacts on migration routes and pasture lands of interest, including environmental contamination and infrastructure development
- Detection, monitoring, and status of annual forest/tundra fires and associated burned areas in pasture and migration routes
- Monitoring, inventories and tracking domestic and wild reindeer herds
- Meteorological conditions – current and predicted

2.1 Pasture monitoring

2.1.1. Optical sensors for pasture quality

One of the first applications of remote sensing to reindeer husbandry was carried out by George et al., (1977), where an inventory of reindeer-range resources was conducted of wild lands in western Alaska using Landsat data. Since then, a number of in-depth reindeer pasture characterization studies looking at a variety of pasture parameters using optical remote sensing sensors have been carried out in Finland, Sweden, Canada, Alaska, Greenland, and Norway using different combinations of available sensors such as Landsat TM, ETM+, Ikonos, ID-LISS, MODIS, supported by GIS, seasonal maps, digital elevation maps, digital topographic maps, and field data. (A few example are by Colpaert et al., 2003; Tamstorf and Aastrup, 2002; Johansen and Karlsen, 2002; Kitti and Kumpula, 2002; Kumpula et al., 2002; Nieminen et al., 2002; Arseneault et al., 1997; Sandstrom et al., 2003; Rees et al., 2003**)**. These studies were able to use these passive optical remote sensing systems to assess pasture quality parameters such as vegetation type, health and distribution and other land-cover features like water bodies, sand, soil, rock, fires, fire scars and infrastructure.

2.1.2. Microwave sensors for pasture quality

Microwave sensing can also be used for assessing pasture quality due partly to that fact that the tundra is a terrain characterized by sparse to moderate vegetation cover and, therefore, a major component of the C-band radar backscatter is the backscatter from soil surface. (Li et al., 1999). It was shown by (Wang et al., 2004), that radar backscatter is positively correlated to Normalized Difference Vegetation Index (NDVI<0.45), when soil is dry and negatively correlated at higher moisture levels. Soil moisture governs the dielectric constant, which enhances radar signatures from wet soils. Nevertheless, Duguay et al., (1999) noted that the tundra vegetation structure is an important factor explaining the large differences in backscatter with freezing. A SAR study of wet tundra, carried out by Belchansky et al., (1995), has also demonstrated the potential for SAR to discriminate up to four or five tundra land cover classes including water, wet sedge tundra; wet sedge tundra/moist non-tussock-sedge, dwarf-shrub tundra; gravel pads and continuous flooding.

2.2. Radio tracking of reindeer herds

A successful means of directly monitoring reindeer is the use of navigation satellites, radio collars, and Geographic Information Systems (GIS). The first such study was carried out by Craighead and Craighead, (1987) with the NOAA/Tiros system. This method makes it possible to gather information about migration movements, rate of travel, seasonal behavior and other habitat features of reindeer herds. The best example of a radio tracking study of reindeer movement is Porcupine Caribou Herd Satellite Collar Project (http://www.taiga.net/satellite/index.html) based on the ARGOS (Advanced Research and Global Observation Satellite) system. A useful summary of some important applications of remote sensing for reindeer pasture monitoring and some management support may be found at http://www.szooek.slu.se/dokument/gis_ workshop/gis_ work shop.htm.

2.3. Fire, snow, and lake monitoring

There are several other different active and passive systems, which could be or are being used to provide useful data and information for reindeer husbandry such as fires, snow, and lake monitoring. For example, forest/tundra fires are the most hazardous natural disaster impacting reindeer husbandry due to fire damage itself as well as the loss of land from pasture use and the interruption of annual migration routes. (Auclair, 1983; Mironenko, 2000) There are various optical remote sensing systems being used for forest fire detection and monitoring (UNEP, 1999; Liew at al., 2001; Justice and Korontzi, 2001). In addition, SAR is starting to be used more extensively to avoid cloud contamination problems, including the Reindeer Mapper project described later in this paper. Radar has not yet been widely used for the detection of tundra fires. Based on MODIS data the MODIS Rapid Response System (MRRS, http://rapidfire.sci.gsfc.nasa.gov/) was created to monitor the global distribution of fires including tundra sub-Arctic and Arctic zones (Justice et al., 2002). On the other hand, snow, one of the most critical parameters to reindeer herds, is an especially important parameter to be able to monitor and assess, particularly as it impacts the herds' ability to find and forage for food. Snow monitoring using optical remote sensing methods for Arctic regions is limited to months with sufficient solar radiation, but passive and active microwave sensors are relatively unaffected by clouds and solar radiation (Tait et al., 2000; Kelly et al., 2004). Space-borne radars with synthetic aperture (SAR) with the ability to get images of Earth surface through darkness and cloud cover with the resolution comparable with the optical sensors are especially useful for snow studies in polar regions (Ulaby et al., 1994). There are a number of studies under way on this subject, including the Reindeer Mapper project, which is also investigating the use of SAR for characterizing snow parameters in reindeer pastures. Finally, Arctic and Sub-Arctic lakes are important natural landscape features of the tundra environment and are sensitive indicators of regional climate variability (Hall et al., 1994; Doran et al., 1996). In

addition, they are very important features in the reindeer migration pathways, particularly, because during premature thaws due to climate warming they become serious hazards to the migrating herds. Studies are being carried out in the Reindeer Mapper project to determine the utility of SAR data in determining the state of snow and ice in reindeer migration routes.

3. PRELIMINARY RESULTS FROM THE REINDEER MAPPER (RM) PROJECT

The main goal of the Reindeer Mapper project is to provide usable, timely information from satellite data combined with traditional, local and other data and information to improve the understanding of and ability to adapt to changes in climate, environment and human activities and their consequences on the ecosystems, economic productivity and human health and well-being of indigenous reindeer herder communities in Northern Russia. During the first year of the study, the RM team initiated the Reindeer Mapper Team Communications System, established several test sites, set priorities for data requirements, analyzed the use of SAR for characterization of the quality of reindeer pastures, and began work on an educational summer field camp for Russian reindeer herder children to acquaint students with these technologies.

3.1. Remote Sensing Observations

Reindeer Mapper remote sensing studies focused initially on the highest priority measurements/data products identified by the reindeer herders on the Reindeer Mapper team – characterization of "pasture quality' for pastures and migration routes (Box 1). We started with a preliminary study of the use of SAR for characterizing the quality of reindeer pasture because it does not rely on the visible part of the spectrum and, therefore, has the ability to provide data regardless of weather or light conditions. The applications of SAR for characterization of vegetation and measuring snow parameters are not well-developed. Initial studies of seasonal changes in SAR backscatter from different kinds of land features in two locations (Anadyr River Research Area (ARRA) and Vaegi Village Research Area (VVRA) in Chukotka, Russia, were carried out for the four seasons of the period between the years 2000 and 2004. Site selection was done based on data availability from the Alaska Satellite Facility (ASF) and on the location of typical tundra landscapes on reindeer pasture areas. Based on these criteria, two sites within the Anadyr district of Chukotskiy Autonomous Okrug (ChAO) were selected. The first site is a nature conservation area north of "Krasnoe" lake along the Anadyr river (Anadyr river research area - ARRA); the second site, a fire risk area south of Vaegi Village (Vaegi Village research area -VVRA).

Results from the first year of the project show (Yurchak and Maynard, 2005), that the SAR data can detect fire scars very well and could be used for fire scar inventory mapping in conjunction with other systems such as the MODIS Rapid Response System and an analysis of tundra lakes' radar properties suggests the possibility for remote assessment of the depth of lakes. It was also possible to observe the snow masking effect (Ulaby et al., 1994) and wet snow (Bagdadi et al., 1997).

Studies showed the capability of SAR to delineate different types of tundra species as well as demonstrate seasonal changes in radar backscatter from tussock and mountain tundra in time series studies. The sensitivity of SAR data to vegetation and snow cover over plains and mountain tundra is demonstrated on time series study of a selected area in the north of ARRA, fig.1 and fig.2.

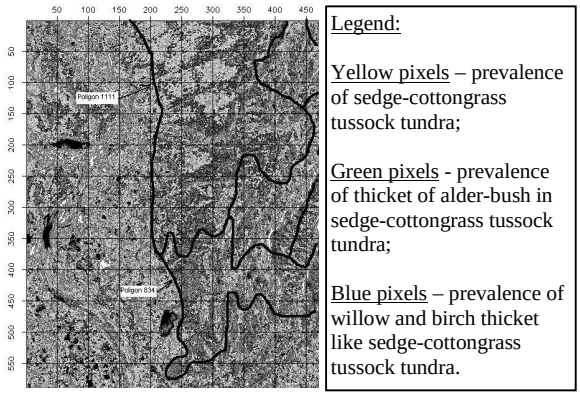

Figure 1. A classified part of SAR low resolution image of ARRA, based on comparison with geobotanical map (courtesy of A. Polezhaev). July 28, 2003. Image size (HxW) ~ 60 x 47 km; image center: $65^0$35'N, $174^0$08'E. © ESA (2004).

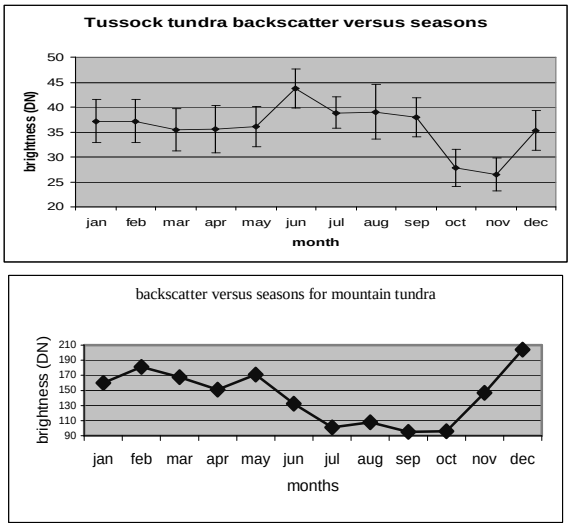

Figure 2. Time series of SAR backscatter from plains tussock tundra and mountain tundra within ARRA.

The results demonstrate clear seasonal changes in tundra radar backscatter. For tussock tundra the backscatter is higher in summer months and drops to the lowest value in the Fall due to decrease of soil (vegetation) moisture because of freezing. The subsequent backscatter increase in the winter can be related to snow cover impact. For mountain tundra, summer backscatter behavior is opposite to that of tussock: it is the lowest. Also, the range of winter-summer decrease is rather high: ~ 60 DN. The reason for such behavior, probably, is different local incidence angles

for tussock tundra (~ 23^0) and for the mountain slope (~0^0). Further field validation work is planned for this study.
In addition, SAR data were shown to be capable of delineating detailed geobotanic polygons. SAR data were compared with ground-based geobotanic maps and were found to provide a higher resolution set of polygons than aerial surveys. These preliminary results suggest that further development of the methodology as well as its validation and calibration may result in a reliable method for SAR applications to these important environmental parameters.

4. SUMMARY

It is clear from this brief review of the capabilities of space technologies potentially useful to reindeer husbandry that there is a rich tool kit of diverse sensors capable of providing valuable information for enhancing the resilience and sustainability of indigenous reindeer husbandry in the Russian Arctic, an unique and important part of the Russian national economy. A number of sensors are capable of providing practical information on the characterization of pasture quality and migration routes, including such parameters as vegetation cover, snow and ice state, infrastructure development and pasture threats and damages from fires. If these observations and data can be made available to the indigenous reindeer herder community on a regular basis to integrate with their local and traditional knowledge for the strongest information base for decision-making, the herder communities could markedly improve their community resilience and ability to adapt to the changes in climate, environment and human-induced activities taking place in their regions.
Preliminary remote sensing results from the first year of the "Reindeer Mapper" project were focused on an evaluation of the highest priority measurements/data products useful for characterizing the land features representing the quality of reindeer pastures using the Synthetic Aperture Radar (SAR). Results from this study show that the SAR data can detect fire scars very well and could be used for fire scar inventory mapping in conjunction with other systems such as the MODIS Rapid Response System.. Studies showed the capability of SAR to delineate different types of tundra species as well as demonstrate seasonal changes in radar backscatter from tussock and mountain tundra in time series studies. In addition, SAR data were shown to be capable of delineating detailed geobotanic polygons. SAR data were compared with ground-based geobotanic maps and were found to provide an even higher resolution set of polygons than aerial surveys. An analysis of tundra lakes' radar properties suggests that SAR may provide a useful means of remotely assessing the state of lakes. In summary, these preliminary results suggest that, with further development of the methodologies as well as validation and calibration studies, SAR has the potential to become a valuable tool for obtaining high-latitude data on these important environmental parameters. Finally, Reindeer Mapper initiated the first phase of an educational project with indigenous children, which brought together remote sensing and computer-based technologies with traditional knowledge in reindeer pastures in Yakutia, Russia.

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