CANADIAN EXPERIENCE WITH ENVISAT ASAR APPLICATIONS; PRELIMINARY RESULTS

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ABSTRACT

In this paper we discuss the preliminary results of five Canadian-led Envisat AO projects (AOEs 368, 373, 569, 576, and 817). The goal of these projects is to evaluate and develop the potential of Envisat ASAR data for application to: landslide monitoring, river ice monitoring, soil moisture mapping, and lithological mapping. As Canadian researchers, our interest in working with Envisat ASAR data is strengthened by the development of the RADARSAT-2 satellite. Our results illustrate the potential of Envisat ASAR data as a source of information in support of the applications discussed. The findings of our river ice monitoring and lithological mapping study clearly demonstrate the effect of polarization on the image information content.

1. INTRODUCTION

The Envisat ASAR system represents the first of a new generation of civilian SAR satellites. Unlike its predecessors, Envisat ASAR has the capability to simultaneously image an area of interest in up to two selectable linear polarizations. The expanded imaging capabilities enhance the information content of the images acquired with regard to the structural characteristics of observed targets, in particular. Consequently, this technical innovation can be expected to improve the utility of Envisat ASAR data products for existing applications and to enable the development of new applications.

As Canadian researchers, our interest in evaluating and developing the applications potential of Envisat ASAR data is strengthened by the development of a Canadian SAR satellite, i.e. RADARSAT-2. The construction of this satellite is well underway and currently its launch is scheduled for December 2005. Like the Envisat ASAR system, the SAR onboard RADARSAT-2 will operate in C-band and have the capability to image in more than one polarization. RADARSAT-2 will have the capability to image in three polarization modes, that is, a selective single polarization, a selective dual polarization, and a polarimetric (quad-polarization) mode. Additional significant technical enhancements embodied by RADARSAT-2 relate to spatial resolution (up to 3m by 3m), look direction (either left- or right-looking), and orbit stability. Besides new imaging modes, RADARSAT-2 will provide all imaging modes of the current RADARSAT-1 satellite. Hence, the satellite will offer data continuity to RADARSAT-1 users and new data that will support development of new applications and refinement of existing ones.

In this paper we will discuss the preliminary results of five Canadian-led Envisat AO projects (AOEs 368, 373, 569, 576, and 817). These projects have in common that they aim to evaluate and develop the potential of Envisat ASAR data, and concurrently of future RADARSAT-2 data, in a particular field of application. The applications addressed in our projects are the following: landslide monitoring, river ice monitoring, soil moisture mapping, and lithological mapping. Our studies are ongoing and will likely accelerate now that Envisat ASAR data products have started to become more readily available.

2. LANDSLIDE MONITORING

2.1 Background

Landslides pose serious threats to settlements, and infrastructure that supports transportation, natural resources management and tourism. They commonly occur with other major natural disasters such as earthquakes, volcanic activity, and floods caused by heavy rainfall. Recent research has shown that differential SAR interferometry can be used to monitor landslide motion. Provided certain sensor and site-specific conditions are met, deformation values of a few cm over the acquisition period can be measured. To avoid loss of coherence non-vegetated areas and image pairs with short time intervals between acquisitions are preferred. Small perpendicular baselines result in the best sensitivity to terrain height differences. Moreover, corrections for the effect of topography are required in order to achieve useful measurements of surface deformation.

In this paper we present the preliminary results of an investigation into the application of differential space-borne SAR interferometry to the monitoring of post failure landslide slope deformation. The results of this

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study will be used in support of the positioning of in-situ motion instruments.

2.2 Study Area

Our study focused on an area on the East face of Turtle Mountain in the Crowsnest Pass region of southern Alberta, Canada. At this location, a 30 x 10^6 m^3 rockslide-avalanche of Paleozoic limestone occurred in April of 1903. This event, known as the Frank Slide, took the lives of seventy people. A 6000 ton rock fall that occurred in 2001 has renewed monitoring programs by the Alberta Provincial Government. The large, non-vegetated slide with its eastern aspect provides an ideal site for satellite-based InSAR experiments.

2.3 Data and Method

ERS, RADARSAT Fine Mode and ENVISAT Image Mode (HH) data were used in our InSAR experiment. By choosing ascending orbit acquisitions we ensured that the look direction (right) would correspond with the aspect of the slope, and gave the desired large local incidence angle on the slope itself. For all data pairs processed, coherence values were generally high on the slide as well as in the accumulation zone. This even was the case for image pairs with very long temporal baselines. For example, the coherence values for a pair of ERS-1 /-2 images acquired 736 days apart (Aug-95 / Aug-97) ranged from 0.73 to 0.91. The topographic phase contribution was removed using a CDED 1:50,000 digital elevation model.

2.4 Results and Discussion

Fig. 1 shows three maps revealing the post-failure behavior of the Frank Slide. The maps were obtained through interferometric analysis of ERS, RADARSAT and Envisat ASAR image pairs, respectively. The ERS deformation map indicates a coherent surface displacement of approximately 2 cm over the 2-year period of along parts of the fault line. This suggests that the failure along the fault line may trigger secondary slides or another rock fall. Thus, these areas are targets for the installation of field instruments. All three C-band SAR satellites used proved useful in monitoring slope deformation, which will vary over the year, peaking generally in late spring, since the slopes are least stable when saturated with water after spring snowmelt. This explains the large displacements shown in the Envisat derived deformation product. RADARSAT Fine Mode data with their higher spatial resolution (~8 m) yield more spatial detail, whereas the well-maintained orbits and ephemeris data of ERS and Envisat allow for more straightforward InSAR processing. Moreover, the extensive ERS-1/-2 data archives permit monitoring since the early 1990s.

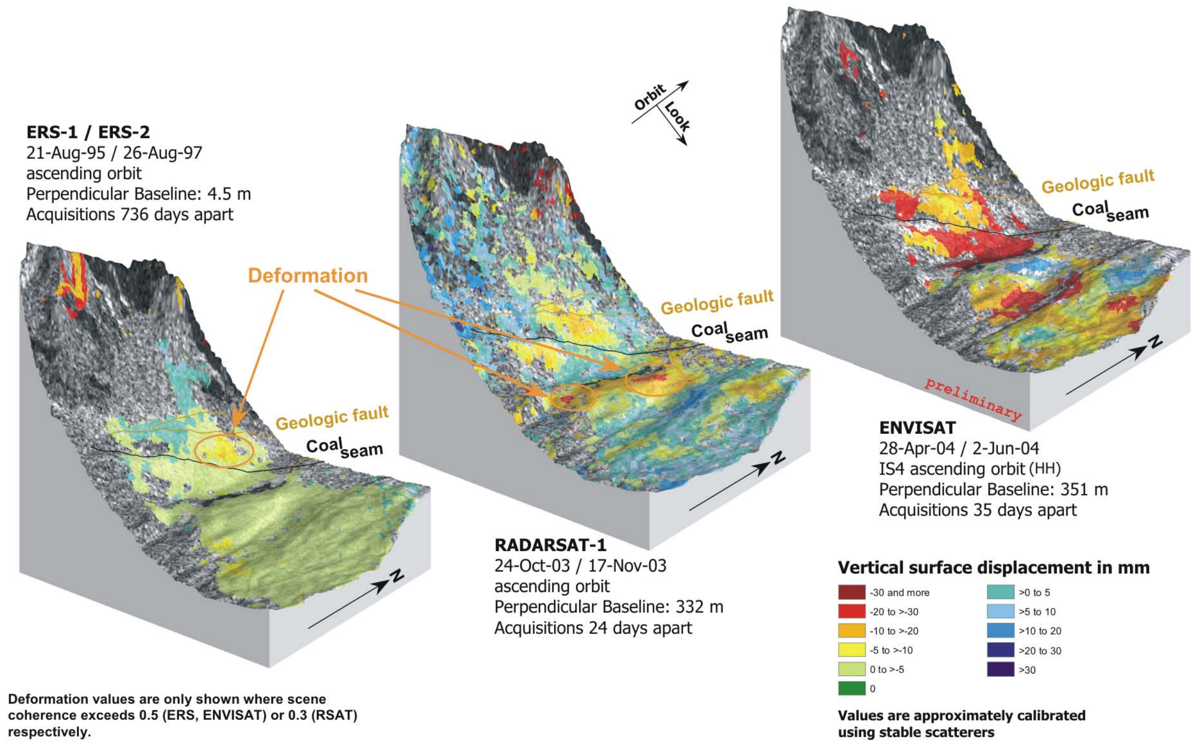

Fig.1. Maps obtained through interferometric analysis of repeat-pass ERS, RADARSAT and Envisat ASAR image pairs showing the post-failure behavior of the Frank Slide, Alberta.

A combination of the synoptic InSAR deformation maps and measurements from field instruments provides a more integrated monitoring system for Frank Slide and other large active slides along strategic transportation routes.

3. RIVER ICE MONITORING

3.1 Background

River ice governs the winter regime of northern rivers and provides seasonal access to northern locations that lack a land-based road network. The impact of river ice on the life of northerners peaks whenever ice jams cause flooding in populated areas during spring breakup (e.g. Badger, New Foundland 2003). The limitations that river ice conditions may dictate concerning water intake or discharge exemplify its impact on northern business operations such as hydropower generation and oil sands exploitation. Up-to-date information on river ice conditions (in terms of coverage, type and thickness) supports the modeling of winter discharge and breakup processes and as such contributes to the wellbeing of northerners. The traditional method of river ice characterization and spring breakup monitoring typically involves visual observation from aircrafts and/or lookouts. Space-borne SAR systems represent a potential alternative source of information in support of river ice monitoring.

3.2 Study Area

Our area of study is the Athabasca River at Fort McMurray, Alberta, Canada. Due to the generally dynamic nature of the spring breakup process this site is at considerable risk of ice jam flooding. Breakup typically progresses as a cascade of ice jam releases through the steep reach upstream of the town of Fort McMurray. Often, these ice runs arrest and jam at the town site were the riverbed is known to level out. From a flood forecasting perspective, it is highly desirable to have prior knowledge of incoming ice runs. The current method for spring ice breakup monitoring involves visual observation, intermittently during aerial over flights and continuously from a lookout upstream of the town site.

3.3 Data and Method

Our study into the potential of space-borne SAR data for application to the monitoring of river ice in the Athabasca River at Fort McMurray was initiated in 2003. In this paper we present the preliminary results of our monitoring study in connection with the 2004 spring breakup. Whereas our 2003 study was solely based on RADARSAT-1 data, our study in 2004 applied both RADARSAT-1 and Envisat ASAR data. The RADARSAT-1 images (10) were typically acquired in the Fine mode, HH-polarization only. The Envisat ASAR images (5) were acquired with alternating polarizations, i.e. HH and HV or VV and VH, in beam modes IS5 and IS6.

Ground reference data were collected prior to breakup in February 2004 and during breakup in March/April 2004. Fieldwork in February 2004 included the characterization of ice types and the measurement of ice thicknesses and snow depths along transects at selected locations across the river. By March/April of 2004 the ice cover was no longer save to access and therefore fieldwork was limited to the characterization of the ice cover by visual observation complemented with hand held photography from an aircraft.

SAR image processing involved speckle filtering (FGamma filter, 2 passes, resulting ENL about 10), geocoding, and the generation of enhanced grey-tone image products and pseudo-colored / density-sliced image products. Density-slicing was performed according to steps of 3 dB. This step size is equivalent to roughly two times speckle induced backscatter standard deviation (ENL ≈ 10).

3.4 Results and Discussion

For the purpose of this paper, we will limit ourselves to a discussion of results that illustrate the effect of polarization on the image information content in terms of ice type and ice/water contrast, in particular.

A combination of a RADARSAT-1 Fine mode image (HH, F2N, $38.9^\circ \leq \theta_{inc} \leq 42.0^\circ$) and an Envisat ASAR alternating polarization image (VV&VH, IS6, $39.1^\circ \leq \theta_{inc} \leq 42.8^\circ$) was used to evaluate the ice type information content as a function of image polarization. The two images were acquired five days apart on February 7 and February 12 of 2004, respectively. Given the time of the year and the short time interval, the ice covers imaged may be considered identical.

The available backscatter range for ice type characterization was found to be similar in the HH and VV polarization (i.e. –26 to –2 dB) but smaller by about 6 dB in the VH/HV polarization (i.e. –26 to –8 dB). The implication of this is, that HH and VV polarized images allow for identification of more river ice types or classes than VH/HV polarized images. This is illustrated by means of the density-sliced and pseudo-colored image products shown in Fig. 2. Nevertheless, the cross-polarized images were found to show more detail in areas of high backscatter, that is, at locations with consolidated ice covers, than like-

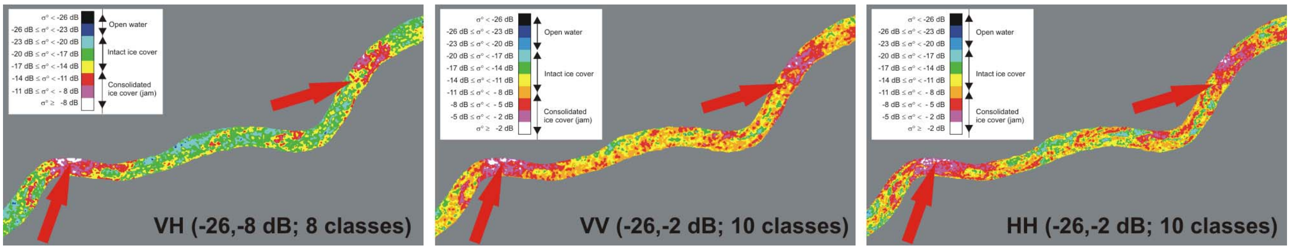

Fig. 2. Density-sliced and pseudo-colored image products showing the ice cover types as found in a section of the Athabasca River. Envisat ASAR acquired the VH and VV image, while RADARSAT-1 acquired the HH image. The arrows mark locations were the ice cover is consolidated.

polarized images. The HH and VV images did not reveal differences in terms of ice type information content.

The effect of polarization on image information content in terms of ice/water contrast was assessed using images acquired during two consecutive Envisat ASAR overpasses in the morning (descending) and evening (ascending) of April 18, 2004. At both occasions, the system operated in Image Mode Swath 5 ($35.8^{\circ} \leq \theta_{inc} \leq 39.4^{\circ}$). In the morning it imaged in HH and HV polarization, while in the evening it operated in VV and VH polarization.

Visual analysis of image products revealed that HV/VH polarized images suffer from a lack of backscatter contrast between ice and water. At the given incidence angle range, the cross-polarized backscatter response of water and (deteriorating) ice appears to fall below the noise floor of the ASAR system. The HH and VV polarized images studied were showed a very similar ice / water backscatter contrast. On average, however, HH polarized images can be expected to show a better ice / water contrast than VV polarized images. This may be explained from the higher sensitivity of the VV polarization to differences in wind condition and the deteriorating effect of higher winds on the ice / water backscatter contrast.

4. SOIL MOISTURE MAPPING

4.1 Background

Estimating the amount of water stored in a soil profile is essential in most water management projects and for assessing the hydrologic state of a basin. In many cases, particularly watershed scale monitoring or modeling, soil moisture is inferred from more easily obtainable hydrologic variables such as rainfall, runoff and temperature. As such, there is a strong need for procedures to estimate soil moisture in a watershed independently from the models. These procedures must provide not only basin average estimates but also the spatial distribution within a basin in order to meet the requirements of emerging distributed models.

In this paper we present results of a study into the potential of RADARSAT-1 and Envisat ASAR data for estimating soil moisture at the watershed scale. Multiple acquisitions collected over the Roseau River watershed, located in Manitoba, for the period of September 2002 through June 2003 were analyzed in relation to ground observations and meteorological conditions. A method was then developed to produce soil moisture maps for input to a hydrological model for flood forecasting.

4.2 Study Area

The Roseau River Basin is a sub-basin of the Red River Basin and covers an area of 5328 km^2 with 2357 km^2 in Southeast Manitoba and the remainder in Minnesota. The basin has a sub-humid to humid continental climate with moderately warm summers, cold winters, and rapid changes in daily weather patterns. About three-quarters of the approximately 500 mm of annual precipitation occur from April through September, with almost two-thirds of that falling during the spring. Low relief, poor drainage and water-saturated soils are characteristic for the basin. The land use consists mainly of agricultural fields in the west, pastures and shrubs in the central portion of the basin, and forests and wetlands in the east. The basin comprises a wide range of soil textures with rich clay soils being dominant in the west and increasingly more silt and sand rich soils in the east.

4.3 Data and Method

Twelve RADARSAT-1 and Envisat ASAR images were acquired for the study in the fall of 2002 and the spring of 2003. RADARSAT-1 operated in the Wide 1 and Standard 4 beam modes that cover incidence angles ranging from 20° to 40°. The Envisat ASAR operated in the Image Mode Swaths 1, 2 and 3, hence covering incidence angles from about 15° to 31°. RADARSAT-1 operated in the (fixed) HH-polarization, while the Envisat ASAR operated in either the image mode (acquiring HH or VV) or the alternating polarization mode (acquiring HH and VV). To avoid the effects of dew on the measured radar backscatter signal, all images were acquired during ascending (evening) overpasses.

Fieldwork involved the measurement of soil moisture, surface roughness and tillage orientation at 22 and 14 representative sample fields in the fall of 2002 and the spring of 2003, respectively. In addition, all sites were photographed and qualitatively described. All fieldwork was carried out within 4 hours of a satellite overpass. Volumetric soil moisture was measured using TDR probes for the top 5 cm of a field. The average volumetric soil moisture content of a particular field was calculated from 15 measurements obtained at five different within field locations. Surface roughness was measured, along the radar look direction, by means of a SRM-200 surface roughness meter. The root mean square (RMS) height and the correlation length are calculated from the SRM photographs. Surface roughness was measured twice at a minimum of three locations per field. Three met-stations continuously monitored the local environmental conditions for the duration of the study.

Radar image processing included the conversion of pixel values from digital numbers to Beta Naught (linear scale), the geocoding of all images to a single grid, the delineation of the sample fields, and finally the extraction of field variables, i.e. average Beta Naught (converted to dB) and central incidence angle. Subsequently, the radar image variables and corresponding field measurements were used to establish statistical relationships by means of regression analysis.

4.4 Results and Discussion

The relationships between radar backscatter and target /sensor parameters including soil moisture, incidence angle and RMS height are presented in Tab. 1. The simple and multiple regression analysis for RADARSAT C-HH and/or Envisat C-HH, Envisat C-VV were all significant ($p<0.05$). The highest coefficient of determination was obtained for Envisat C-HH with volumetric soil moisture, incidence angle and RMS height as independent variables ($R^2=0.80$). In most cases, the addition of RMS height did not significantly increase the coefficient of determination. This can probably be explained by the fact that most fields were of similar roughness. Therefore adding the RMS height does not improve the model enough to justify the addition of a third independent variable in the model. Following regression analysis, selected models were inverted to calculate volumetric soil moisture at the basin scale, that is, for 5 km grid cells containing agriculture pixels. The soil moisture values obtained will be used as input for the WATFLOOD hydrological model.

5. LITHOLOGICAL MAPPING

5.1 Background

When compared to the lithological discriminations possible from optical multi-spectral and hyperspectral

Tab. 1. Summary of regression analysis for radar measurements and Soil Moisture (SM), Incidence Angle (IA) and Root Mean Square (RMS) roughness. * means statistically significant at the probability level less than 0.05.

Sensor	Variables		Regression Results		
	Dep. Var.	Ind. Var.	n	R^2	Regression Equation
Radarsat C-HH	dB	SM%	115	0.182*	y = -9.8867 + 0.1918x
	dB	SM%, IA	115	0.532*	y = -0.5033 - 0.3544(IA) + 0.1697(SM%)
	dB	SM%, IA, RMS	87	0.587*	y = -1.5852 - 0.3768(IA) + 0.1246(SM%) + 0.1448(RMS)
Radarsat & Envisat C-HH	dB	SM%	152	0.200*	y = - 9.2070 +0.2152x
	dB	SM%, IA	152	0.599*	y = 1.6374 - 0.4216(IA) + 0.1765(SM%)
	dB	SM%, IA, RMS	113	0.625*	y = 0.4546 - 0.4354(IA) + 0.1201(SM%) + 0.1413(RMS)
Envisat C-HH	dB	SM%	37	0.517*	y = -6.8168 + 0.2721x
	dB	SM%, IA	37	0.717*	y = 2.0751 - 0.3861(IA) + 0.2090(SM%)
	dB	SM%, IA, RMS	26	0.803*	y = -2.1486 - 0.4220(IA) + 0.2994(SM%) + 0.2282(RMS)
Envisat C-VV	dB	SM%	43	0.407*	y = -5.0141 + 0.2029x
	dB	SM%, IA	44	0.467*	y = -0.4474 - 0.2527(IA) + 0.2102(SM%)
	dB	SM%, IA, RMS	31	0.317*	y = -0.7805 - 0.2914(IA) + 0.1719(SM%) + 0.0982(RMS)
Envisat C - HH/VV	dB	SM%	31	0.030	y = 0.2192 - 0.0169x
	dB	SM%, IA	31	0.033	y = -0.1446 + 0.0194(IA) - 0.0169(SM%)
	dB	SM%, IA, RMS	20	0.260	y = -1.738 + 0.0147(IA) + 0.0146 (SM%) + 0.1751(RMS)

imaging systems, radar is unable to provide any direct compositional information about bedrock. However, radar does yield information related to the surface roughness, i.e. terrain information that is unavailable from other Earth observing systems.

In cold regions, freeze-thaw cycles commonly break-up the surface of the bedrock. The fabric of the rock typically controls this mechanical weathering. Thus, different rock types may exhibit different surface roughness. The capabilities of SAR to map differences in surface roughness can facilitate geological mapping.

5.2 Study Area

A variety of sedimentary rock types are exposed on Bathurst Island, Nunavut (N75°/W99°). These rocks weather into loose and fragmented rock particles that create fine mineral soils to angular block fields (felsenmeer) with a wide range of surface roughness. As such, this environment provides a rich test site for examining the effect of radar imaging parameters on the potential of SAR to provide terrain roughness information in support of lithological mapping. In this paper, we will demonstrate the effect of C-band HH and HV polarization.

5.3 Data and Method

Envisat ASAR Alternating Polarization (HH and HV) data were acquired on 19 December 2003. The ASAR operated in the IS-4 beam mode to achieve moderate incidence angles (31.0°-36.3°) and resolution suitable for regional mapping. By acquiring data during the winter months, that is, under dry and frozen ground conditions, we were able to avoid the variable contribution of soil moisture and wet surfaces to the radar backscatter. The radar data acquired were converted to Sigma naught and geocoded. Required field data, including surface roughness measurements, had been collected at an earlier date.

5.4 Results and Discussion

The HH and HV image presented in, respectively, Fig. 3a and 3b show an area of Bathurst Island that comprises two contrasting rock types. The dark image regions (1) represent siltstones (Bird Fiord Formation) where rock fragments have an average size of 17 mm, but lie in a matrix of finer material. The brighter arcuate image regions (2) correspond to fossiliferous carbonates of the Eids and Blue Fiord beds. Here, the rock fragments are larger and average 46 mm across.

Although not visible in Fig.3, quantitative analysis of the radar measurements shows that the backscatter contrast between the two surface types in the HV

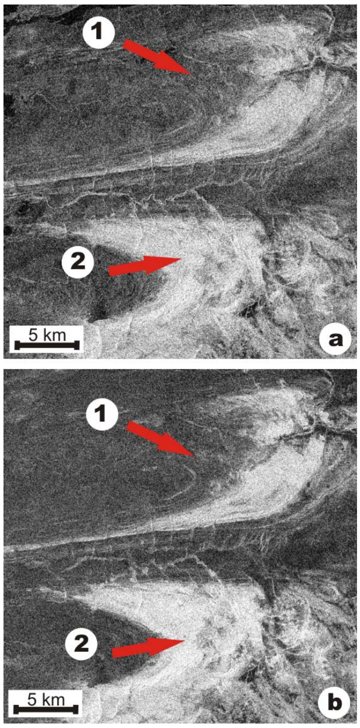

Fig.3(a-b). Envisat ASAR IS-4 image showing Bathurst Island, Nunavut, Canada. Acquired on December 19, 2003. (a) HH-polarization (b) HV-polarization.

polarization is larger than in the HH polarization. The contrast in HV and HH were found to be 9.4 dB and 6.9 dB, respectively. The larger contrast in HV demonstrates the superior sensitivity of this polarization to differences in surface roughness. On the other hand, visual comparison of Fig. 3a and 3b shows that terrain features such as minor layering and drainage networks are more clearly discernible in HH than in HV.

6. SUMMARY

We have demonstrated the potential of Envisat ASAR data as a source of information in support of the monitoring of landslides and river ice and the mapping of soil moisture and lithology. The results of our river ice monitoring and lithological mapping studies clearly illustrate the advantage of the polarization diversity as offered by the Envisat ASAR.

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