Investigation of ERS SAR Data of the Tandem Mission for Planning and Monitoring of Siberian Pipeline Tracks

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Abstract

Siberian pipelines, embedded in a mosaic of boreal forest, bogs, rivers, lakes and tundra, are undergoing stress due to varying heave displacements by thawing and freezing of the active permafrost layer. Problems such as the upward movement of the lighter gas pipelines arise due to the melting of frozen surface water in spring, or the downward movement in winter caused by the melting of the frozen soil around the pipeline. These varying movements of the pipeline, depending on the underground, the surface cover and the pipeline itself, may lead to cracks and severe damage. These problems require a permanent monitoring of existing and a careful planning of new pipeline tracks. Currently the pipelines are regularly monitored by visual inspection via helicopter. Planning information such as a DEM and a classification of the surface cover is derived mainly from optical remote sensing and field work. The potential of radar data as a possibly more reliable and cost effective source of information for the monitoring and planning of gas pipelines in the remote and hardly accessible regions of Nadym, Siberia, was investigated. Methods used included the interpretation of multitemporal SAR backscattering as well as SAR interferometric products using ERS-1/ERS-2 Tandem data. ERS SAR data proved to be a valuable alternative for the mapping of the pipelines. The study is being carried out as an ESA Pilot Project (A02.D129) and funded by the German Space Agency (DARA).

Keywords: ERS-1/2 SAR data, InSAR processing, Cartography, Pipelines, Monitoring, Siberia

Introduction

The all-weather capacity and illumination independence of spaceborne Radar remote sensing offers new opportunities for planning and monitoring of pipeline tracks in the remote and inaccessible areas of the West Siberian Lowlands. In this taiga biome, land surfaces and their artificial structures undergo up and downward displacements caused by the thawing and freezing of the active permafrost layer. A careful monitoring of existing pipeline tracks and a precise planning of new pipeline tracks is required. The localization of these impacts improves the assessment of the potential hazards. The Active Microwave instruments on board ERS 1- and ERS-2 satellites, launched by ESA, deliver SAR data for this task. A promising technique, where the ERS-SAR data of two passes are combined, is Interferometry. This technique allows the derivation of height and height displacement maps. Further, SAR Interferometry has shown great potential for the mapping of land surfaces (Wegmüller et al., 1995).

Test Site and Data Description

A test site in the environs of Nadym (latitude 65°30´N, longitude 73°15´E), located in the northern part of the West Siberian Lowlands, has been selected for investigation. As Permafrost underlies most of the region the gas pipelines and other man made structures are exposed to heave displacement. Fig.1 shows the area of investigation as seen by Landsat TM. Two gas pipeline tracks, surrounded by a mosaic of vegetation, meandering river channels and little thawing ponds cross the test site. In the TM image the pipeline tracks and dust roads appear in bright blue colors. They are embedded in open boreal forest (coniferous forest) which appear in light greenish brown colors. The sparse woods with moss show up as violet and the closed forest of the floodplain (mixed forest) as brown. The greenish areas with little lakes indicate peatland and swampy areas. The red regions are moist depressions with grasses and light green tones occur on burnt areas where fresh vegetation now grows.

In general, pipelines are constructed subsurface, as shown in Fig. 2 B. The pipelines are not visible themselves but can be detected indirectly by changes in the vegetation cover caused by their construction. The large pipeline track running from NE to SE consists of 9 subsurface pipelines and has a width of about 1 km. In some areas the pipelines are not covered with sand, but are exposed on the surface (see Fig 2 A). This is mainly in areas where surface water occurs and where the active permafrost layer is very thin and ice is close to the surface (peatland and swamp).

Ground truth campaigns were carried out during August 1995 and 1996, for additional verification the Landsat TM scene of 26/07/95 (see Fig. 1) has been studied. All the subsets which will be discussed later on are displayed as rectangles in Fig. 1. Radarsat Fine mode data, acquired on 05.09.1996 with a pixel spacing of 6.25 m, was included for analysis.

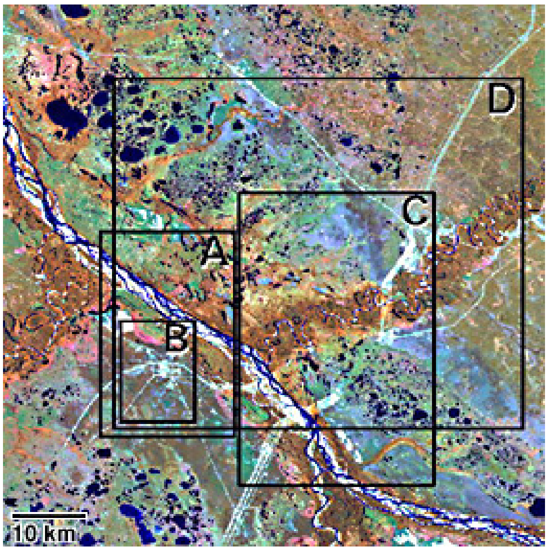

Figure 1: Test Site Nadym, Siberia, as seen by TM -RGB(4,5,3) Composite

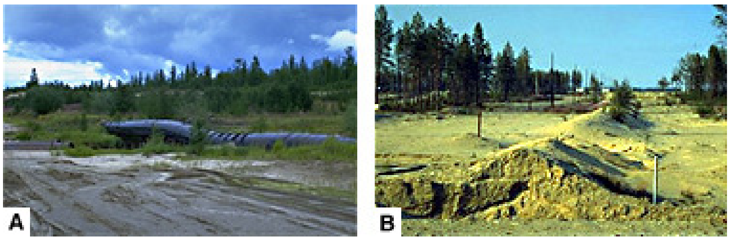

Figure 2: Pictures of a surface (A) and subsurface (B) pipeline

The following data sets from the tandem phase of ERS-1 and ERS-2 (descending orbits, frame 2277) have been analyzed. The scenes are listed together with meteorological data acquired next the airport of Nadym in Tab. 1. The empty cells indicate unavailable information.

Orbit	Date	Temp.C	rel. Humidity %	Wind speed m/s	Precipitation
E1-22839	27.11.95	-29.0	74	1	Snowheight 15cm
E2-03166	28.11.95	-24.8	80	1	
E1-24843	15.04.96	-2.5	91	5	Snowheight 60 cm
E2-05170	16.04.96	-3.5	67	3	
E1-25334	20.05.96				
E1-25845	24.06.96	17.7	75	7-10	
E2-06172	25.06.96	12.4	67	6	

Table 1: ERS-SLC Tandem data sets and meteorological information

Data Processing

The ERS-SLC scenes have been processed by Gamma Remotes Sensing AG using their Interferometric SAR Processor (ISP). Common spectral-band filtering in azimuth and range was applied. The scenes have been co-registered to a subpixel accuracy. The 5-look intensity images have been calibrated and Frost filtered using a 5x5 pixel window. The coherence was computed adaptively with varying window sizes from 3 x 15 looks for areas of high coherence up to 9 x 45 looks for areas of very low coherence. RGB composites composed of the adaptive filtered coherency images in red, the amplitude of the first date in green and the ratio of the two dates in blue, have been produced. Prior to the ratio calculation (intensity ERS1/ERS2) the amplitudes have been Frost filtered using large 15 x 15 pixel windows, in order to account for the strong signal noise of SAR images.

A useful combination of ERS SLC pairs has been selected for evaluation. The next table lists the orbits for each pair, the time difference in days, the perpendicular baseline and adaptive coherence mean.

InSAR Pair	Time difference in days	Baseline B perp in m	Adaptive Coherence Mean
22839_3166	1	77	0.73
24843_25344	35	42	0.09
24843_5170	1	57	0.67
25344_25845	35	100	0.09
25344_6172	36	17	0.08
25845_6172	1	82	0.51
5170_25344	34	99	0.10

Table 2: Orbit, Time difference, Baseline and Coherence for investigated ERS Tandem Data

All the tandem pairs show a high coherence mean, whereas the 34,35,36 day repeat cycles with an average coherence around 0.1 do not meet the requirements for Interferometric exploitation. Cinsequently, the image pair 22839_3166 has been selected for DEM generation.

The absolute height information has been derived using 15 Ground control points of known topographic height from the map. The only topographic map available has a scale of 1:500,000. For the 15 GCPs the average deviation between the interferometric height estimates and the reference height error standard deviation of the control points is about 5m. The elevation is given in the geometry of the map used to select the control points (probably related to Geoid surface as the used Geoid of the reference map is unknown).

All the data sets (ERS, Radarsat, TM) have been geo-referenced to the ortho-rectified coordinate system which is represented in UTM, WGS 84.

Data Interpretation

The next figures 3 A and B show the intensity and coherence data for the subset A as indicated in Fig. 1 . Following features are indicated: compressor station (reference point (rp) 1), pipeline track (rp 2) and a power line corridor (rp 3). One can clearly depict the linear structures in the coherency image (see Fig. 3 B) which can be hardly detected in the intensity image (see Fig. 3 A). In the coherency image the non forested areas do have a high coherence compared to the low coherence of the forested areas. The major reasons are orientation of the sensor to the object (see rp 2 and 3) and the ground resolution (rp 3). This clearly demonstrates that the coherency image successfully allows the detection of pipeline tracks and other man-made objects whereas the intensity image does not.

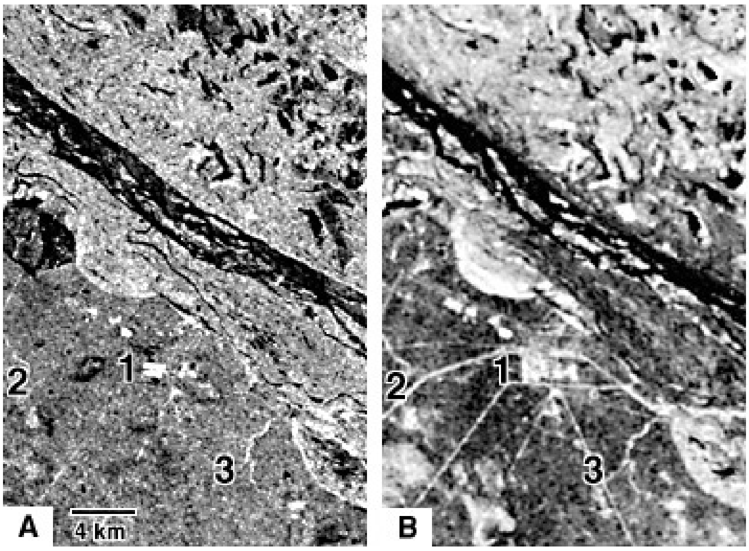

*Figure 3: **A** ERS Intensity Image 25.06.95 **B** ERS Coherence Image 24/25.06.97*

The Fig. 4 A shows the uncalibrated amplitude of the frost filtered Radarsat Fine Mode (descending orbit) for the subset B (see Fig.1). A delineation, derived from Radarsat Fine Mode data Fig. 4 B, gives an overview of the prominent features. In the Radarsat image the pipeline tracks are black. This is most likely due to the low incidence angle (causing a broader radar shadow). A zoom-in along the power lines shows the typical effect of a bright signal for the pylons caused by the HH polarization. The higher resolution (pixel spacing of 6.25 x 6.25 m) allows a clear detection of all features.

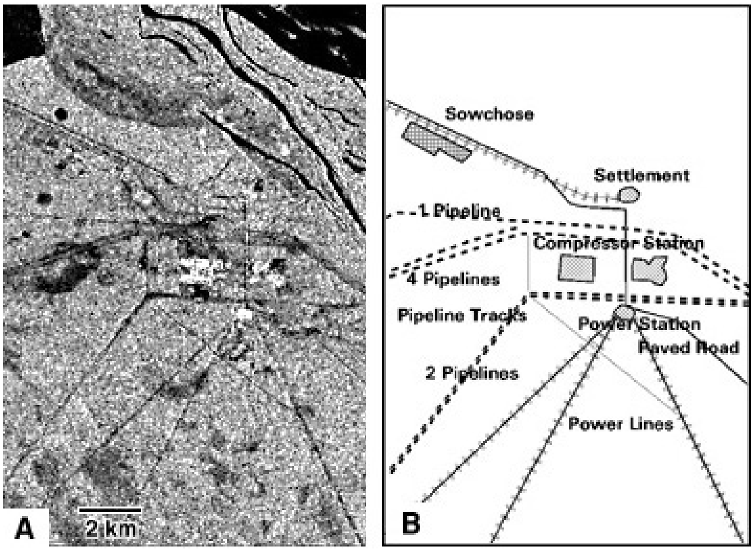

*Figure 4: **A** Radarsat Fine Mode Image **B** Delineation of Radarsat Image*

Multitemporal intensity images for the subset C (see Fig.1) are displayed in Fig. 5 A, B and 6 A, B.

Fig. 5 A shows the pipeline tracks Yamburg (rp 1) and Urengoi (rp 2) during dry winter conditions on the 27.11.95. The temperature is -29.0 ° C and the area is snow-covered (15 cm). The 1 km wide pipeline track Yamburg (which includes 9 subsurface sand- or short vegetation covered pipelines) is clearly visible in the environs of the open boreal forest (see region around rp 1). The backscatter of the pipeline varies due to changing surface cover which depends on the locality and construction work (grasses, bushes (region around rp1); no trees and only sand (region around rp 3); or mosses in the peatland areas or no cover at all (rp 6).) In the floodplain forest the pipeline track (rp 3) is almost invisible due to the similar backscatter. In the environment of peatland and permafrost (rp 4) the pipelines are detected very well. This may be due to the snow-covered frozen tundra which has low intensities contrasting increased intensities of the single pipeline itself.

Fig 5 B shows the same situation on 15.04.96, at an air temperature of -2.5 ° C and a snowheight of 60 cm. From personal communication we know that the area is extremely frozen. At the pipeline track Urengoi (rp 5) construction work has been undertaken. In order to replace the sand-buried pipelines they first need to be dug out. Furthermore, an ice road has been built to cross the river and to access the pipeline track. The change of geometry (slope of the sand hills exposed to the sensor look direction) increased the backscatter. The moist depression (linear dark features) next to rp 1 is extremely frozen. The dirt road is now very bright and gives a high reflection caused by the change of geometry due to traffic and snow removal. All the construction work along the pipeline has to be undertaken in winter because in summer there is no access.

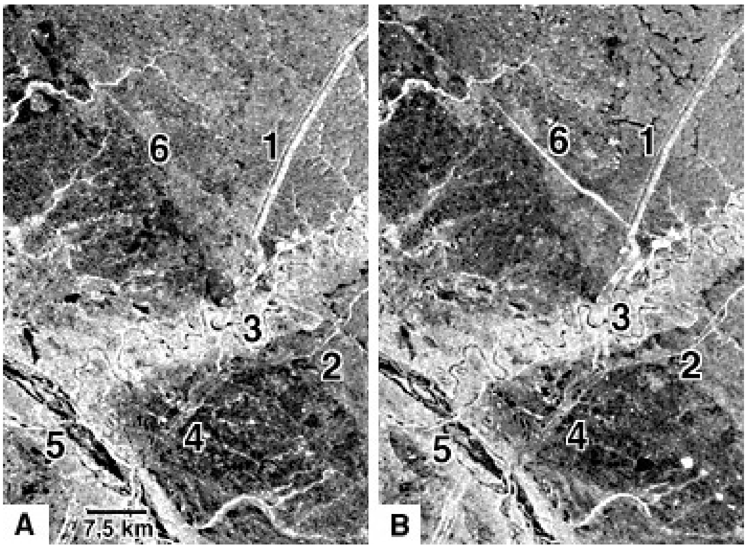

*Figure 5: **A** ERS Intensity 27.11.95 **B** 15.04.96*

Fig. 6 A shows the area of investigation on the 20.06.96, when thawing starts and the snow is melting. A clear distinction between the moist loamy peatland areas with short vegetation (rp 4) and the well drained sandy soils where the open forest and sparse forest is located (rp 2), is obvious. An increase in backscatter of about 3 dB due to moisture changes can be observed for the peatland environs. As well sparse forest stands with moss can also be distinguished from open forest stands. The border is located near rp 2. The pipeline track in the area around rp 4 cannot be located due to similar backscatter.

Fig. 6 B shows the date of 24.05.96 at a temperature of 17.7 º C. The area is snow-free, a lot of surface water occurs and the thawing ponds are ice-free (see rp 4). The pipeline track Urengoi is now better depicted at location 4. Burnt areas appear very bright (south of rp 1).

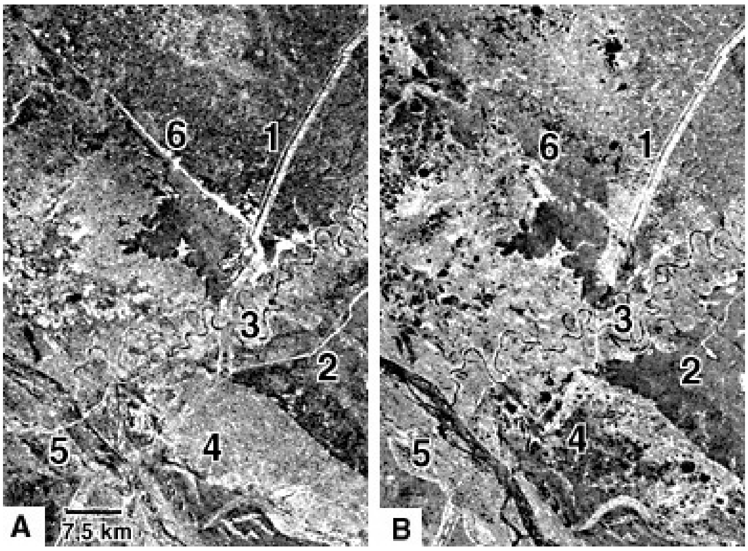

*Figure 6: **A** ERS Intensity 20.05.96 **B** 24.06.96*

The interpretation of the multitemporal images gave the following results: detection of construction work during winter, occurring moisture changes in the pipeline vicinity (extreme changes on badly drained loamy soils (peatland, bog, swamp)), and small changes on the well drained sandy soils where forest stands; this allows the determination of freezing and thawing, whereas the pipeline itself is stable and shows hardly any changes in the backscatter.

The next figures (Fig. 7 A /B and 8 A) show the multitemporal coherence for subset C (see Fig1.). The value of the coherence depends on the following factors: geometry (baseline) and parameters related to the land surfaces. The latter can be further separated into volume scattering and temporal changes such as movement of the scattering object (wind effect) or variation in dielectric constant (freezing and thawing).

The overall coherency for the 27./28.11.95 tandem pair, displayed in Fig. 7 A, is very high (0.7). The small baseline and the stable meteorological conditions (frozen, snow-covered environment) favors this. Clearly visible by its low coherence are moist depression, thawing ponds and river channels. This is due to the temporal de-correlation induced by movement of the scatter and change in the dielectric constant (freezing) see Fig. 9.

Fig. 7 B presents the coherence information for the ERS tandem pair of 15./16.04.96. Clear differentiations between forested and non-forested areas are visible. The low correlation due to volume scattering in the mixed forest of the floodplain (rp 2) is obvious. The areas covered with short vegetation show high coherence due to frozen environment. The decrease in the correlation of the floodplain forest (see Fig.9) might be related to the particular snow conditions. Currently we are not certain about the exact reason. The road below rp 1 shows low coherence due to truck traffic (in the Intensity Images the roads appear bright). The frozen river (north of rp 5) shows a high coherence.

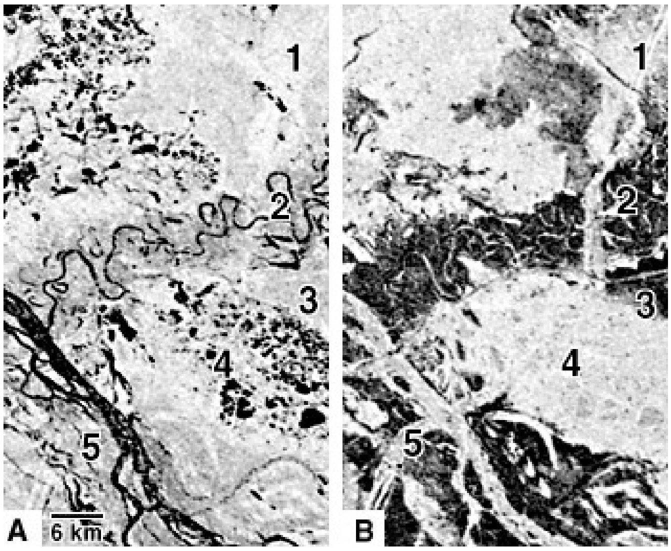

*Figure 7: **A** Coherence Image 27./ 28.11.95 **B** 15./16.04.96*

Fig. 8 A provides an overview of the subset for the ERS Tandem Pair 24./25.06.96. The varying coherence gives a better differentiation. Now all the thawing ponds (see rp 4) and the river (NE of rp 5) have a low coherence due to movement of water by wind. Even the string bogs crossing the pipeline track next to rp 5 can be detected.

Fig. 8 B shows the same subset C (see Fig.1) for the area investigated in an RGB composite combining coherence data as red, the intensity of 24.06.96 as green and the backscatter changes as blue. The next table (Tab. 3) indicates the colors and the associated features.

Color	**Coherence of ERS 24./25.06.96 (R)**	**Intensity of ERS SLC 24.05.96 (G)**	**Ratio of the Intensity 24./25.05.96(B)**	**Feature**
Blue	Low	Low	High (Change)	River, surface aater (rp 4)
Green	Low	Medium	Medium (No Change)	Flood plain forest (rp 2)
Yellow	High	High	Medium (No Change)	Young short vegetation (rp 1), pipeline track in peatland environment (rp 4) and covered with short vegetation
Red	High	Low	Medium (No Change)	Sand covered pipeline tracks

Table 3: Legend for Fig. 8 B

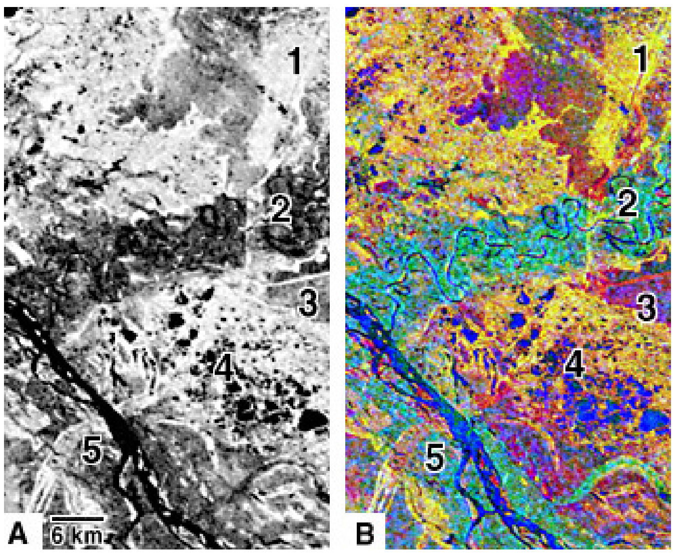

*Figure 8: **A** Coherence Image 24./25.06 **B** RGB Composite 24./25.06.96*

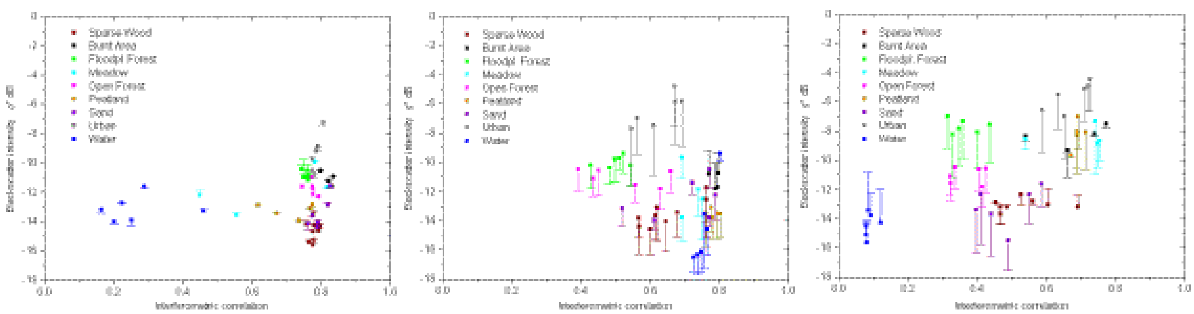

Figure 9: Backscatter Changes / Interferometric Correlation for ERS Tandem Pairs of Nov 95, April 96, June 96

The investigation of the multitemporal coherence images together with the backscatter changes enables a classification of the landscape itself and a classification of the surface of the pipeline tracks. It also allows the determination of the freezing and thawing conditions of the area investigated.

Conclusions

It has been demonstrated that, in general, the following products can be derived from InSAR processing of ERS- SAR Tandem data for Planning and Monitoring of pipeline tracks in boreal environments:

A. Digital Elevation Model (relative accuracy 5-20 m rms in height, horizontal resolution is about 20 - 30 m) which is important for planning of new pipeline tracks. Products such as shaded relief, slope maps and contour lines can be derived.

B. Landcover Classification showing the

- hydrological situation (lakes, rivers and moist areas) for planning of placing concrete weights to prevent upstroke of lighter gas pipelines in spring when ice thaws.
- geo-location of pipeline tracks, power lines, roads, compressor stations and settlements.
- vegetation cover and its classification in potentially hazardous areas (through freezing and thawing of moist areas).

The next table (Tab.4) indicates the tasks used as input for planning and monitoring of pipeline tracks in boreal environments, and the products used.

TASK	PRODUCTS USED
DEM for planning of new pipeline tracks	Tandem pair most preferably in stable climatic condition during winter (Nov. ,Dec.)
Landcover classification for planning and monitoring	Multitemporal coherence images (For the Nadym test site the coherence of Nov. pair shows very well the hydrological situation; the April pair is best for forest and non-forest classification.)
Geo-location of pipelines and related infrastructure	Coherence images and Radarsat images (for the Nadym test site April and Nov. pair)
Determination of potentially hazardous areas	Multitemporal ERS intensity. Most preferable are data sets from winter and spring when thawing starts
Monitoring of construction work	Multitemporal ERS intensities

Table 4: Requirements and products used for Pipeline Monitoring and Planning

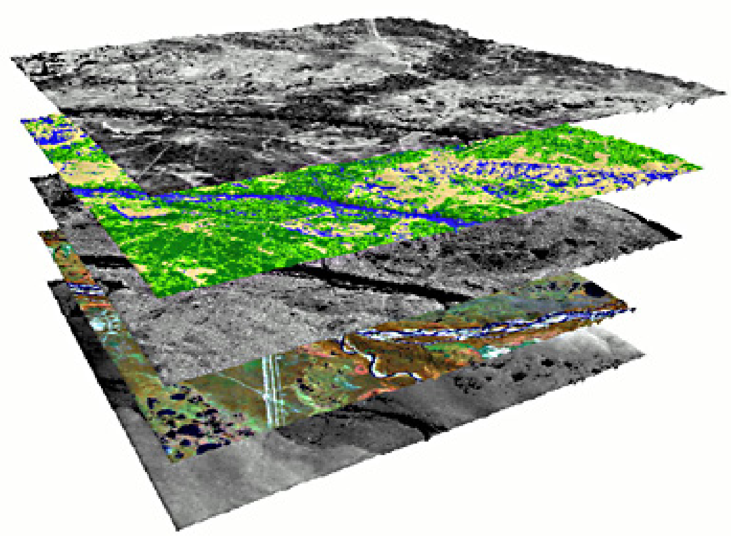

Figure 10: Multi-Layer 3 D Animation for the Pipeline Tracks

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References

Askne, J. , Hagberg, J. , 1993
Potential of Interferometric SAR for classification of land surfaces. *Proc. IGARSS 93*, pp. 985-987.
Rignot, E., Way, J. B. 1994
Monitoring Freeze and Thaw Cycles along North-South Alaskan Transects Using ERS-1 SAR. *Remote Sens. Environ. 49*, pp.131-137.
Rosen, A., et. al. 1994
Interferometric Detection of Freeze-Thaw Displacements of Alaskan Permafrost Using ERS-1SAR. *Proc. PIERS ´1994*, pp.842-845.
Streck, C., O. Hellwich , 1996
Retrieval of Man-Made Structures in Siberia with INSAR-Techniques using ERS-SAR Data. *Proc. IGARSS 96,* p.p. 1836-1838.

Wegmüller, et al., 1995
Land surface analysis using ERS1/2 SAR Interferometry. *ESA Bulletin*, *No. 81*, pp.30-37.