Oil pollution monitoring by SAR imagery

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Abstract – Russia is the first world gas producer and the second for oil. Its reserves of hydrocarbons are primarily located in the Russian North where permafrost is often present. Large oil spills occur in this area. The pipelines are subject to corrosion and cryogenic processes. The risk of rupture increases consequently. The oil spill monitoring is limited by the vastness and the frequent inaccessibility of the pipeline network and therefore, requires remotely sensed data. The ability of ERS Synthetic Aperture Radar (SAR) data in the detection of Usinsk's oil spill, which occurred in 1994, is carried out in this study Moreover, some disturbing factors such as the characteristics of the sensor, the sensor look direction, the topography and the speckle, make difficult the SAR data processing. In fact, the determination of the features of the target depends on the knowledge of these disturbing effects. Examples of such features presented here are interpreted based on the regional and temporal context of the SAR imagery as well as the morphology and temporal persistence of the features. Thus, the digital image processing techniques included radar backscatter calibration, speckle filtering, edge detection filtering, brightness value (dB) analysis and oil spill shape analysis are used to enhance the spillage area in the ERS imagery over the Usinsk's area. The method developed here using 3 SAR images is discussed especially in terms of limits and possible uses as a routine.

Keywords: Hydrocarbons, pollution, radar imagery, pipeline, Russia, Arctic.

1. INTRODUCTION

Oil spills occur in the Russian North where permafrost is often present. The pipelines are subject to corrosion and cryogenic process. The risk of rupture increases consequently. The oil spill monitoring is limited by the vastness and the frequent inaccessibility of the pipeline network and therefore, requires remotely sensed data. Hence, SAR image data are relevant to detect oil spill on land surfaces of Russian North, due to its ability to overcome the night-times limitations of optical images, the cloud-cover limitations of infrared images and for large scale of remote land monitoring.

Oil spill is recognizable on SAR image as a dark patch, because it decreases locally the radar backscatter on most of land surfaces in the Russian North [1]. The area with lower backscattering values appears darker in SAR image and as a concavity on a radar cross section. The information of each pixel in radar image is carried by backscattering coefficient or radar cross-section, in σ^0 dBs. SAR image is affected by the speckle, a noise with a grainy appearance created by radar waves due to the different distances of trajectory from targets or multiple reflections scattering. Speckle damages radiometric resolution and disrupts the task of human interpretation and scene analysis. Hence, it is necessary to apply filter for reducing speckle without losses of image properties which is unavoidable on oil spill segmentation. Moreover, some disturbing factors such as the characteristics of the sensor, the sensor look direction, the topography make difficult the SAR data processing. We propose a procedure for oil spill detection in ERS-1 SAR image data of Usinsk's accident based on an adaptative filter to reduce speckle on image with assumption that the speckle is a multiplicative noise, combined with linear filtering and morphological mathematics techniques for feature extraction on oil spill segmentation.

2. MATERIALS AND METHODS

2.1 Case Study

The spill took place along a section of pipeline connecting Vozey to Usinsk, some 50 km north of Usinsk (longitude 57° 20' E, latitude 66° 30' N), near the Arctic circle. A succession of some leakage occurred during the summer of 1994. Consequently, a big earthen dam was built to prevent oil spreading away from the pipeline. The large oil reservoir built up behind this dam leading up to a significant rupture between August and September.

2.2 Image Processing

Several procedures exist for oil spill on sea surface analysis from SAR images. Nevertheless, automatic analysis of SAR images on land surfaces is not applied routinely yet. Most of spill accidents have shown that they must be supervised. In this cases, results have to be obtained. In order to obtain operational analysis, the first step is to locate the spill and its contours. This can be carried out by several methods such as gradients, filters, morphological mathematics, etc.. The second step is to determine the nature of the spill by classification. We focus mainly on the detection step using simple procedure.

Three ERS-1 precision images (PRI, mid-swath incidence angle 23°) of the spill area were analysed with the following dates in 1994: August 3, August 20 and September 29. The pixel size is 12,5 * 12,5 m and the resolution is 25 * 25 m. The dates were chosen to cover the period from the time when the spill was contained by the dam to a date after the dam had broken.

Pre-processing was carried out. Disturbing factors due to the sensor such as its characteristics and its direction were corrected by ESA. Then, the ERS-1 images were geometrically corrected using the UTM projection (UTM N40) and the spheroid of Krasovsky.

2.3 Speckle filtering

SAR image data is affected by a multiplicative speckle noise, a consequence of image formation under coherent radiation. Speckle damages radiometric resolution and disrupts the task of human interpretation and scene analysis. Adaptative filters based on a appropriate scene and speckle model are the most fitting filters for SAR images because they preserve structural and textural features. These filters such as Lee filter, Kuan filter, etc. used multiplicative speckle model and local statistics. On this paper, the Frost filter is applied as the basis of speckle filtering to improve image quality for better estimation than those above [2]. The Frost filter was designed as an adaptative Wiener filter that assumes an autoregressive exponential model for the scene reflectivity. The resulting value R for the smoothed pixel is:

$$R = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} P_{i,j} w_{i,j}}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}} \qquad (1)$$

where the weighting value $w_{i,j}$ is:

$$w_{i,j} = \exp\left(-A * T_{i,j}\right) \qquad (2)$$

$$A = D * \left(\frac{\sigma}{\mu}\right)^2 \qquad (3)$$

where D = exponential damping factor
μ = mean value of intensity within the window
σ = standard deviation within the window
$T_{i,j}$ = the absolute value of the pixel distance from the center pixel to its neighbours in the filter window
$P_{i,j}$ = grey level of each in the filter window and $w_{i,j}$ is the weight for each pixel.

In this study, speckle was reduced on intensity images using a 5*5 window size and D equal to 1 (Figure 1).

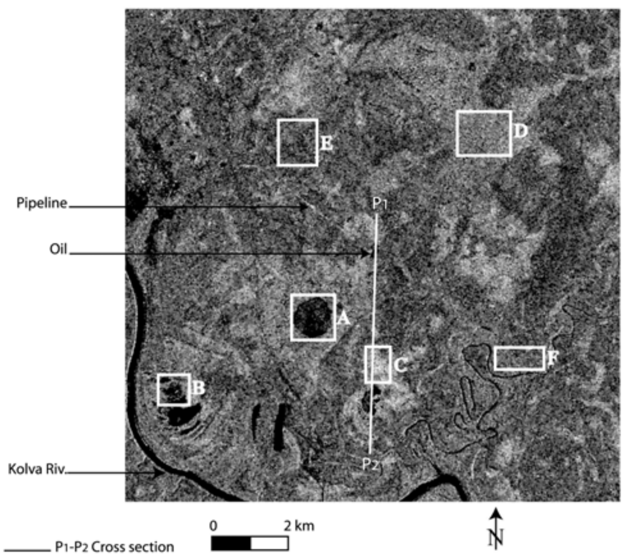

Fig. 1. ERS-1 SAR image (08.03.1994) and main responses of land surfaces (A. Lake, water. B. marshy places. C. bare and moist soils. D. moist soils with short vegetations. E. dry soils with short vegetations. F. Oil. P_1-P_2 cross section.)

2.4 Detection of oil spill using linear filtering

To generate radiometrically calibrate images that allow data to be quantitatively related to the physical targets on ground, radar backscattering calibration was carried out. The backscattering coefficient, σ^0 in dBs [3] is:

$$\sigma 0 = 10 * \log\left(\frac{I_{i,j} * \sin\left(\theta_{i,j}\right)}{K * \sin\left(\theta_0\right)}\right) \qquad (4)$$

where $I_{i,j}$ = the pixel intensity
θ_0 = the angle incidence of image center pixel
$\theta_{i,j}$ = the angle incidence of the pixel
K = the calibration constant given by ESA

The dampen effect of oil spills has been widely studied [4-6]. Oil spills are mainly characterized by their low backscattering with respect to the background. In many cases, the mean backscattering coefficient is estimated from the image and the threshold is set to x dB below this mean. Thus, the prior knowledge of land surface backscattering coefficients is required.
However, each land surface has its own temporal dynamic. The mean backscattering coefficient of background varies even in homogenous land surfaces, due to the environmental effects. Therefore, a simple procedure is to use a multi-temporal approach. To estimate a significant damping effect, a standardized low-pass filtering was carried out. The Hamming low-pass filter is defined by its impulse response:

$$H_i = \begin{cases} 0{,}54 + 0{,}46\cos(2\pi i/n) & \text{if } i \in \{1, \ldots, n\text{-}1\} \\ 0 & \text{else} \end{cases} \qquad (5)$$

where n = twice the number of samples in spatial frequency before the cut-frequency.

In this study, the filtering of SAR images was carried out with n equal to 18. Figure 2 shows the dampen effect of oil spill illustrated by the development of a concavity near the pipeline and towards the south. Nevertheless, the contours are blurred due to the losses of high frequencies information by the filtering.

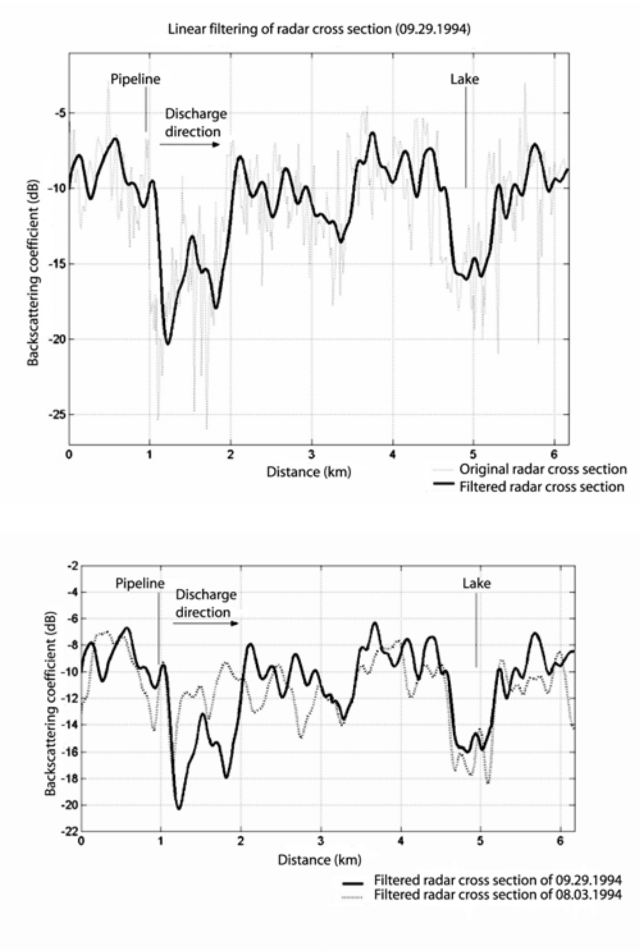

Fig. 2. Original and filtered radar cross section (P_1-P_2) of ERS-1 SAR images (08.03.1994 and 09.29.1994).

2.5 Detection of oil spill using non-linear filtering

A procedure to overcome this previous drawback is non-linear filtering. Non-linear filters are more useful to obtain a correct estimation of the background, the land surface. They can detect the slow variations of the land surfaces and preserve the contours of the dark patch, the spill. The procedure is in two steps. The first step is to reduce the variations of high backscattering coefficient land surfaces and to enhance low backscattering coefficient surfaces. The second step is to determine the contours of low backscattering coefficient surfaces.

First, an opening [7] of the speckle reduced image was carried out. The structural element is a square of 9 *9 size. Figure 3 clearly shows a concavity and the possibility to locate oil spill without confusion. However, an image whose reading is “unpleasant” was generated by the filtering.

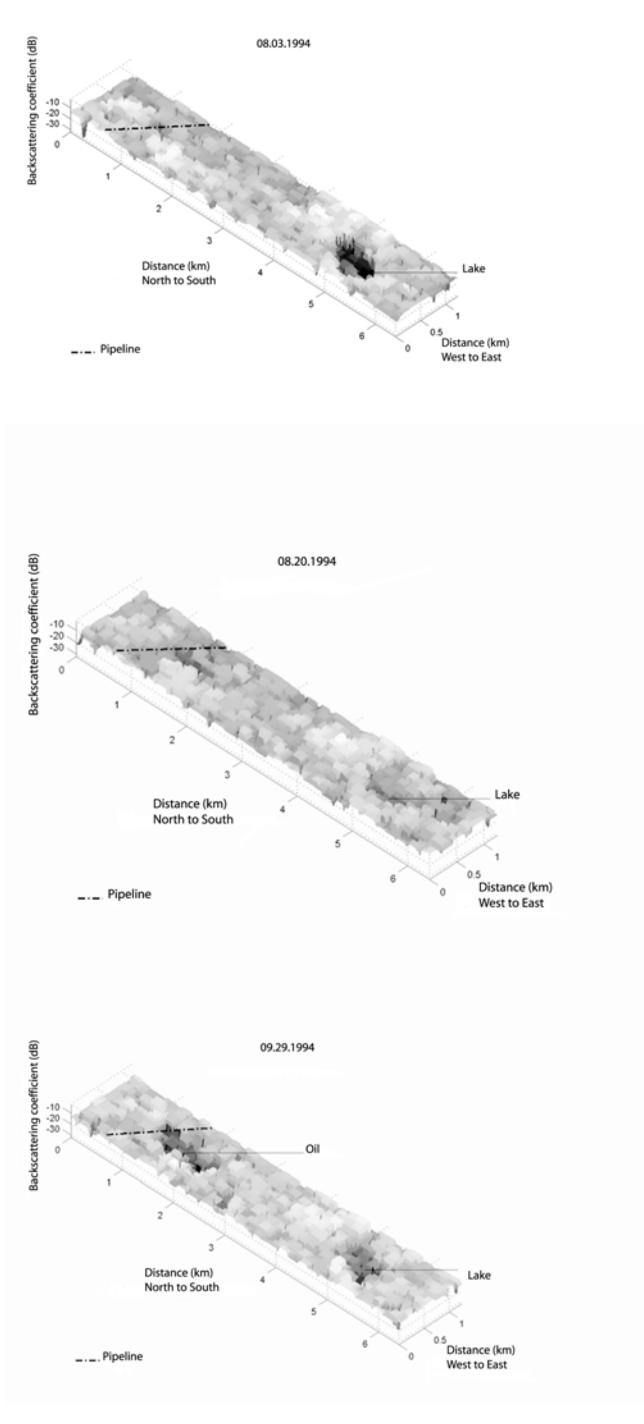

Fig. 3. Temporal Dynamics near the pipeline (based on P_1-P_2).

Secondly, instead of detecting the contours on the original image, it is better to detect them on a less noisy image whose contrasts are enhanced as well as the level of the dark patch. Thus, a “top-hat” filter [47], with a 3 * 3 window size of the structural element, was applied to the previous image to determine the contours of the oil spill. Figure 4 shows the enhanced oil spill and complete the analysis.

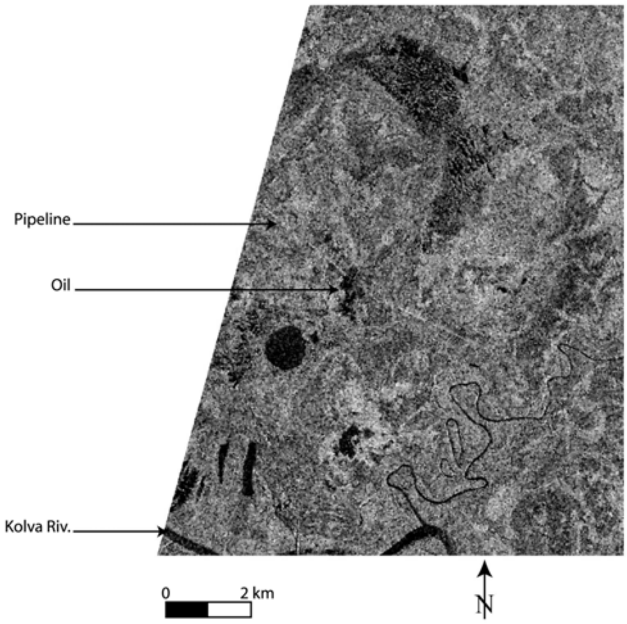

Fig. 4. Filtered ERS-1 image (09.29.1994) using a “top-hat” filter.

3. CONCLUSION

SAR images analysis is done in two steps: the detection of oil spill using linear and non-linear filtering. The detection of oil spill using linear filtering has shown an enlargement of oil spill area near the pipeline and towards the south. While the backscattering coefficient of the background is about -10 -12 dB, a brutal fall down to –20 dB is recorded in the polluted area. It is widely lower than the mean backscattering coefficient of –7,2 dB for the land surfaces. The analysis also reveals that this brutal fall can not be linked to the temporal variability of the background calculated from the three SAR images. This temporal variability of land surfaces about +/- 4,7 dB can not explain the decrease down to –20 dB due to oil spill without confusion. The detection of oil spill using non-linear filtering allows to determine more precisely the size and the shape of the oil spill. Before August 20 the oil size is estimated to 1 300 m², while September 29 it is evaluated to $2{,}89.10^5$ m². However, this evaluation probably underestimates the quantification of oil spill. Indeed, the detection of spill requires a sufficient presence of oil to lower backscattering coefficient of land surfaces.

Finally, SAR appears to be a suitable instrument to study oil spills on land surfaces, well adapted because of its ability to overcome the night-times limitations of optical images, the cloud-cover limitations of infrared images. Moreover, it allows instantaneous coverage for large scale as wide as 100 * 100 km of remote land monitoring. Nevertheless, the procedure does not allow a clear quantitative study due to the underestimation of the oil spill size.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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