ERS DINSAR observations of gas pipelines located in permafrost area of Siberia

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ABSTRACT

The idea of the report is a discussion of applicability of repeated orbits SAR interferometry technique for monitoring of gas pipelines in permafrost areas with a goal of the detection of pipes displacements. Eleven ERS SAR scenes obtained in 1993-1998 were combined in interferometric pairs and interferograms of various qualities were synthesized. The displacements of a pipe as well as modifications of surrounding soils state were discovered on many interferograms. An uplift of pipes because of soils frost heave is clearly seen on the one-year interferogram. Sinking of pipes because of underlying permafrost thawing is seen on the tandem pair obtained during one-day interval. The results mentioned demonstrate the possibility of the detection a centimeter scale vertical displacements of pipes by means of spaceborne repeated orbits SAR interferometry.

INTRODUCTION

Radar observations of Earth in the scheme of repeated orbits interferometry come to be modern remote sensing technique, which allows compiling digital terrain models and to monitor dynamics of the surface cover occurred between the observations. Such a C-band radar systems as RADARSAT (Canada), ERS-2 and ENVISAT (European Space Agency), are used widely and with success for the repeated orbits radar interferometry.

METHODOLOGY

An interferogram is generated usually as a result of pixel-based complex multiplication of the signals s_1 and s_2, acquired in the different spatial points of the signal scattered from the same surface elements:

$$s_1 s_2^* = A_1 A_2 \exp\left(j\left(j_1 - j_2\right)\right) = A_1 A_2 \exp\left(jk\left(r_2 - r_1\right)\right),$$

where A_1 and A_2 – signal amplitudes, r_1 and r_2 – slant ranges of observation points till the surface element, $\hat{e}$- wave number.
The relief heights variations are represented in the signal phase difference $\Delta\Phi_{topo}$ on the interferogram via the displacement of the fringes from the nominal position, which is determined by the observation geometry (the relation between the phase difference and relief heights variations is described elsewhere, see for example [6]). Local displacements of the scattering surface elements in the slant range direction during time interval between acquisitions as large as Δr_{dyn} also cause an extra phase shift as large as $\Delta\Phi_{dyn}$, which is equal:

$$\Delta\Phi_{dyn} = -\frac{4p}{l}\Delta r_{dyn}.$$

The phase shift mentioned also become apparent on the interferogram as a displacement of the fringes from their nominal location. One of the problems of the repeated orbits interferomertic observations lies in the separation of the influence of relief from surface displacements. A use of three or more repeated orbits observations in the differential interferometry scheme allows solving this task.
The pioneering and most impressive results were obtained form the analysis of ERS SAR data over the seismoactive area of Landers on June 3, 25 and August 8, 1992, what allowed to mark out tectonic displacements of the surface at centimeter scale in the area of the break as a consequence of earthquake occurred on June 28, 1992 [1,2]. The

observations of displacements of sea ice covers because of sea tides as well as displacements of sludgy coastal soils are described in [3-6].

The idea of application the differential interferometry techniques for lengthy artificial objects monitoring in the permafrost area was discussed widely by many researchers. Verification of this opportunity of interferometric mapping was made by authors of the report in the framework of «AO Exploitation projects» using ERS SAR data obtained over the section of Yamburg-Nyda pipelines in 1993-1998.

For the mentioned above task of monitoring the state of Yamburg-Nyda pipelines we have selected 11 SLCI images from ESA archives. The selection of interferometric pair was limited by a number of factors. Size of spatial interferometric baseline was taken into consideration first of all. The next one was a temporal baseline or the time interval between the acquisitions as its increase is a reason of the growth of signals decorrelation.

RESULTS

Temporal decorrelation is the least for the ERS tandem pairs with 1 day repeat interval. Maximal time interval in our dataset was 5 years with spatial baseline of 30 meters. The best quality of the interferograms was in two tandem pairs from January and June 1996. For all other combinations with larger temporal baseline under even smaller spatial baselines (till 40 m) temporal decorrelation was significantly higher till total decorrelation.

An example of image and interferogram fragment for a pair Autumn 1997- Autumn 1998, presented on a Fig. 1, earnestly displays the possibilities of interferometric observations for the detection of gas pipes dynamics. Here the brightness variations from black to white correspond to 2π phase difference variations, or slant range difference variations at ERS half wavelength size. In spite of 2π phase ambiguity or 2.6 cm vertical displacement ambiguity modern phase unwrapping techniques (see for example, [7]) allow to get phase measurements of higher band of values. The strip on the interferogram in the area of gas pipe indicates the location of the pipe displacements between the SAR observations. Hence a visual analysis of interferogram allows detecting the pipes displacements of centimeter scale. The reason of the pipes displacements in our case is a frost heave, what is typical in a given region with widespread permafrost.

Analysis of the June24-25, 1996, tandem interferogram gave us most unusual results. ON the interferogram from a Fig. 2 we can clearly see vertical displacement of pipes during one-day time interval. The reason of the gas pipes subsidence at a fraction of centimeter being discovered here is in melting of frozen soil under the pipe. Local phase difference shift may be observed also in the area of extensive swampy sites (not shown here), as evidence of small-scale subsidence of swampy soils because of flood discharge from swamps. Other fragments of the full ERS scene contain examples of car road subsidence.

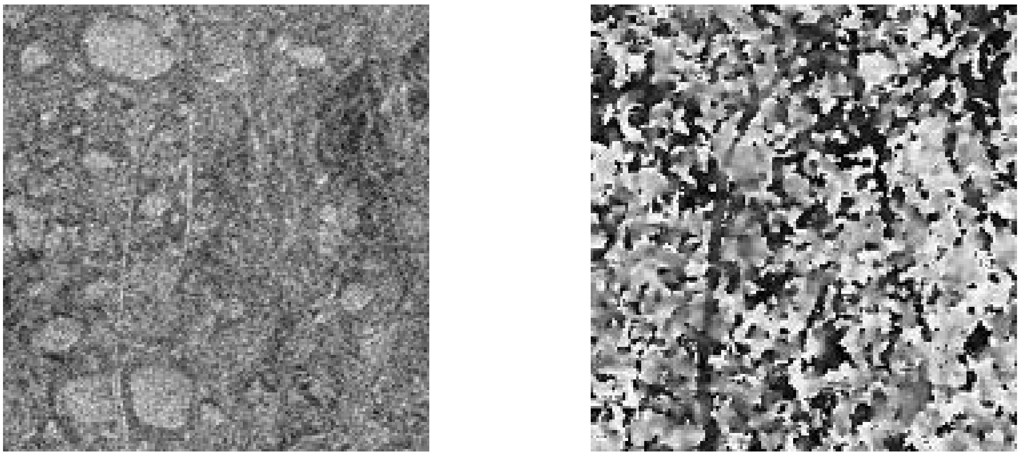

Fig. 1. Amplitude image (left) and interferogram (right) of the gas pipes observed with one-year time interval.

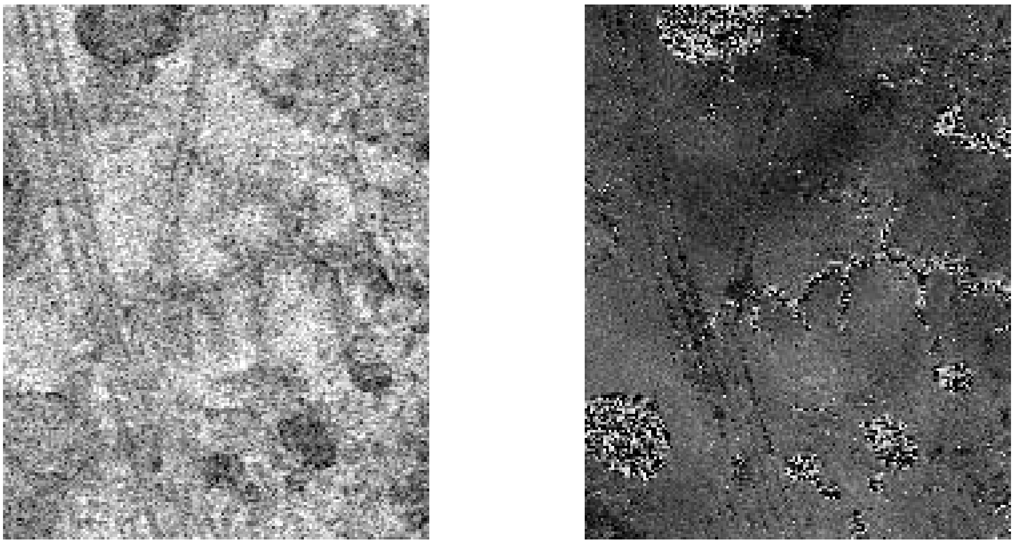

Fig. 2. Amplitude image (left) and interferogram (right) of the gas pipes from tandem pair obtained by ERS1/2 in June 1996.

Unique chance to check reliability of conclusions about the presence of gas pipes dynamics on the tandem pair from June 24-25 appeared because of availability of another tandem pair from January 1-2, 1996. Spatial baselines in these pairs were almost identical, consequently the manifestation of topography on the interferograms should be similar and all the distinctions might be explained by the surface dynamics on one-day interval. Analysis of winter tandem pair from does not reveal any linear structures as it takes place on summer interferogram.

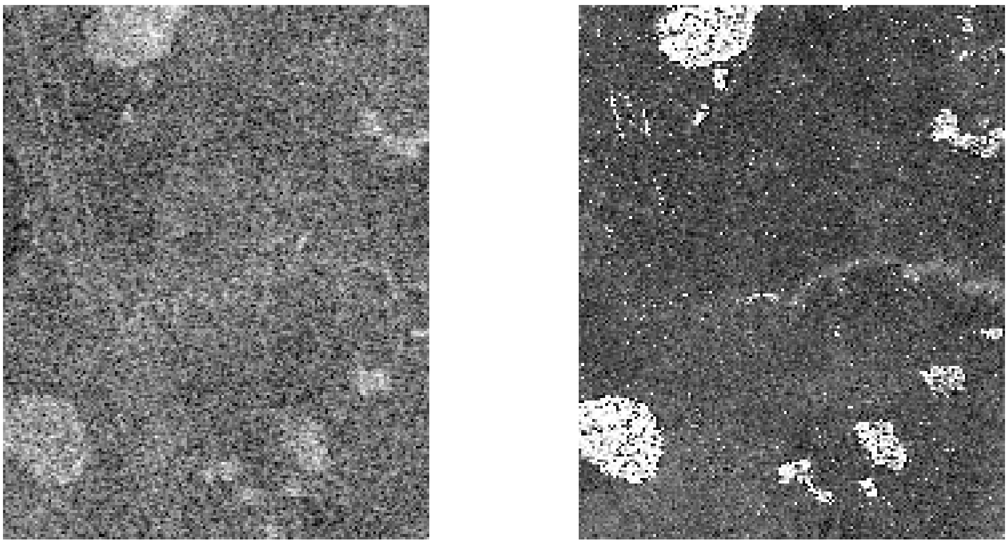

Fig. 3. Amplitude image (left) and interferogram (right) of the gas pipes from tandem pair obtained by ERS1/2 in January 1996.

The absence of the dynamics on the winter tandem pair (see the interferogram on a Fig. 3.) is a result of soils freeze and surface stabilization.

CONCLUSIONS

Thus, the radar observations in the repeated orbits interferometry scheme allow detecting small-scale displacements of the scattering surface during time interval between the observations. An increase of time interval leads to the decrease of signal coherence till total decorrelation, though the amplitude of the effect to be observed will increase in a case of monotonous displacements of the surface.

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