DEFORMATION MEASUREMENT WITH REPEAT PASS AIRBORNE INTERFEROMETRY[1]

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ABSTRACT

River dikes can deform and eventually burst due to extreme high water conditions. This deformation should be measurable with repeat pass SAR interferometry. An experiment with the PHARUS SAR was carried out to verify this. Two flights were carried out with 5.5 days in between them. During the data acquisition on the second day the dike was deliberately deformed. Interferogram analyses showed that the dike deformed by at most 2 mm on this day, in approximate agreement with tachymeter measurements. Unfortunately, the coherence of the interferograms formed by the data of the separate days was too low to measure deformation.

INTRODUCTION

Due to extreme high tide river dikes can lose their stability. This is forewarned by increasing deformation which should therefore be monitored. Conventional deformation measurements (e.g. levelling) are point measurements, and are in addition costly and time consuming. The objective of this work was to demonstrate the capability of airborne SAR interferometry to measure cm-level deformations (spaceborne SAR cannot be used because of the low revisit rate). In order to reach this goal two measurement flights were carried out with the PHARUS C-band SAR [1], while a small dike segment was forced to deform during the second flight.

THE EXPERIMENT

Two flights were performed on 12 and 18 September 2001[2]. The dike was imaged about 10 times during each of these with ~15 minutes in between the images. The flying height was 6000 m, and the incidence angle at the dike 55 degrees. All images were processed to about 1.2 m azimuth and 5.1 m slant range resolution.

Two corner reflectors were put on the deforming dike segment, another two for reference purposes on nearby stable land. On 18-9 the dike was forced to deform by pumping water underneath it and loading it with concrete blocks, all during high tide. In addition the hinterland was dug off. Reflector levelling showed a downward deformation of 5-7 mm between 12-9 and 17-9, and 19 mm between 17-9 and 18-9 (the measurements were done some time before and after pumping). This proves that the pumping etc. of 18-9 was effective.

The perpendicular baseline of every pair of images is less than a few tens of meters. This implies a coherence loss below ≈10 % due to baseline decorrelation. Azimuthal beam steering was not initialised correctly, which implied some coherence loss which varies with the aircraft attitude.

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[1] The Survey Department of the Dutch Ministry of Transport, Public Works and Water Management financed this research.

[2] For brevity's sake 12-9 and 18-9 will refer to the two measurement dates from here onwards.

INTERFEROGRAM ANALYSIS

Four interferograms were analysed, which are discussed in the next sections:

1 Run 1/7 of 18-9 (≈2.5 hour time span). This interferogram includes part of the deformation induced on 18-9. Moreover, the interferogram will have a high coherence due to the short time span.
2 Run 1/3 of 12-9 (≈27 minute time span). This interferogram should exhibit no deformation, because no deformation was caused on this day. It is used as a check for interferogram 1.
3 Run 1 12-9 / run 1 18-9 and run 3 12-9 / run 1 18-9 (≈5.5 day time span). These interferograms should reveal about 5 mm deformation (deduced from corner reflector levelling).

The Run 1/7 18-9 Interferogram

Fig. 1 shows the magnitude, coherence and phase of this interferogram. It is a subsection of the larger 10 km squared interferogram.

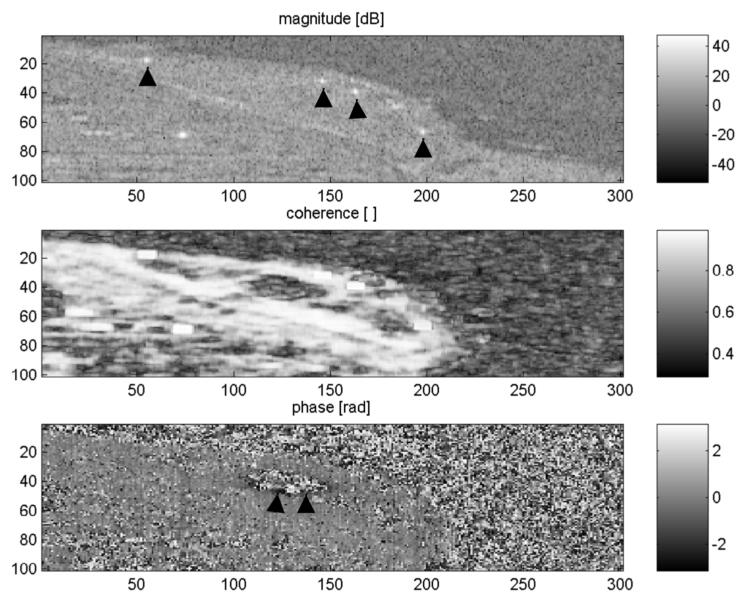

Fig. 1. From top to bottom: magnitude (in dB's), coherence and phase (rad) of the test area. The images are 330 m in azimuth (which increases from left to right) and 300 m in slant range (which increases from top to bottom). The river Lek is at the top (low coherence, noisy phase).

The corner reflectors are indicated by the four black rectangles in the magnitude image. The middle two ones are near the borders of the test area (measuring only 70 m×50 m) which was deformed.
The coherence image shows that the dike with reflectors has a coherence near 0.9, while the area behind the dike (the hinterland) is incoherent (coherence of about 0.4. This rather high value is due to the small template size). This area was dug off to make deformation more probable. It was therefore lower than the surrounding area and quite moist, with puddles occurring at many places. This caused the low coherence.
At first sight the phase image at the bottom shows no signs of deformation, because it is fairly homogeneous. This is in seeming disagreement with the fact that i) it was forced to deform by pumping etc. and ii) the levelling results of the two reflectors on the dike. The only hint at deformation is the black border around the non-coherent area in the hinterland, indicated by the two black triangles. Comparison of the phases of the centre two reflectors to those of the (stable) outer reflectors led to the conclusion that

the centre reflectors had changed in height by at most ±2 mm, which confirms the absence of any substantial deformation.

Tachymeter data was available at some 50 positions in the test area for about every 20 minutes. These were used to compute a map of the radial deformation. This map was co-registered to the interferometric phase image (a subsection of Fig. 1) by using the surveyed reflectors. The result is shown in Fig. 2.

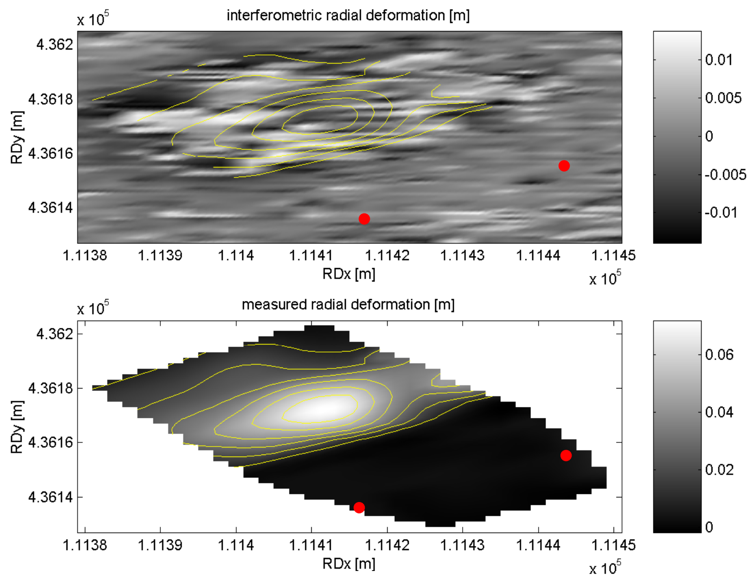

Fig. 2. Comparison of interferometric phase (top) and tachymeter data (bottom). Deformations are in meters (see greyscales at the right).

The map at the bottom shows an area of deformation with a maximum of some 7 cm. The red dots indicate the two corner reflectors located on the dike, which exhibited 5±2 mm deformation according to the tachymeter data (the levelling results that indicated 19 mm dike deformation cover a larger time span than this interferogram). This is in approximate agreement with the 2 mm derived from the interferogram. The yellow contour lines are copied to the phase image at the top for easy reference. A remarkable fact of the phase image is that the incoherent (noisy phase) area corresponds (almost) exactly to the deforming area. On the other hand, the dike and its immediate surroundings are coherent. The incoherence of the hinterland is due to the water on the surface. At the top left of the phase image is a dark patch (the black border in the phase image of Fig. 2) which seems to be coherent. The deformation corresponding to the patch's phase is in approximate agreement with the tachymeter measurements.

The Run 1/3 12-9 Interferogram

This interferogram looks quite similar to the one of run 1/7 of 18-9. Corner reflector response analysis gave that the accuracy of deformation measurement with PHARUS is about ±2 mm if reflectors are used. Fig. 3 compares the coherence of the test area on 12-9 and 18-9. The black arrow (in the 18-9 coherence image) indicates that the hinterland (which was coherent at 12-9) was incoherent at 18-9. This shows that we simply had bad luck on 18-9. Otherwise the coherence images are quite similar.

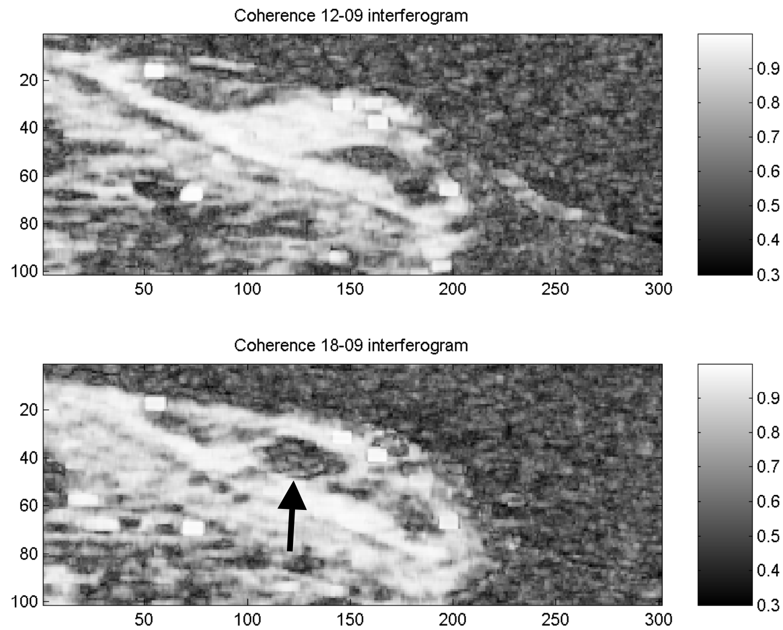

Fig. 3. Coherence of the test area and its surroundings on 12-9 (top) and 18-9 (bottom; see also Fig. 1). The two white rectangles near coordinates (150,40) indicate the positions of the two corner reflectors put in the test area, on the dike.

The Run 1 12-9/Run 1 18-9 and Run 3 12-9/Run 1 18-9 Interferograms

The coherence of both these interferograms is too low to derive deformation information. This lack of coherence can be due do imaging errors (i.e., a too large baseline) or temporal decorrelation. The ERS SAR (also C-band) coherence of grassland can easily be above 0.5 for a 30 day temporal baseline. However, it will be smaller if the weather conditions are bad during or near the acquisitions, as was the case for the second flight over the river Lek. Further analysis of the flight should reveal what the real cause of the low coherence is.

CONCLUSIONS

An experiment with the PHARUS C-band SAR was carried out to measure dike deformation. Two flights were carried out with 5.5 days in between them. Although the dike deformed by a few centimetres between 17-9 and 18-9 interferogram analysis showed that the deformation during the 18-9 interferogram time interval was at most 2 mm. This was approximately confirmed by tachymeter data (5±2 mm). The coherence of the interferograms formed by the data of the separate days was too low to measure deformation.

REFERENCE

[1] P. Snoeij, P. Hoogeboom, P.J. Koomen, B.C.B. Vermeulen, H. Pouwels, "Design and calibration of the PHARUS polarimetric airborne SAR*", 2nd Int'l Airb. Remote Sensing Conf.*, 24-27 June 1996, San Francisco