SHALLOW SUBSIDENCE IN THE DUTCH WETLANDS ESTIMATED BY SATELLITE RADAR INTERFEROMETRY.

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INTRODUCTION

The western part of the Netherlands has a typical Dutch landscape with fen-meadows that consist of wet pasture lands with drained peat soils alternated by natural and artificial lakes, ditches, reed swamps and quaking fens (see fig. 1). This area has been and is still being continuously drained, so as to keep the land dry and suitable for agriculture, pasture and residence. Water levels are artificially controlled in the region by local water management authorities.

Figure 1. Wetlands in the western part of the Netherlands.

This drainage has resulted in subsidence of a couple of meters over the last centuries. As a result, the polders with fen-meadows now lie 1–2 m below sea level. In addition to that, we also find deep polders which used to be large lakes and were reclaimed in the 17th century for agricultural use. Presently, these polders are 2-6 m below sea level. The continuing subsidence of the surface in the polders and the rise in sea level caused that about 25% of the Netherlands is now being situated below mean sea level (up to 6.7 m). Without dikes and dunes 65% of the land would be flooded daily. This situation makes the Netherlands vulnerable to storm surges and river floods.

The ’Green Heart’ (Groene Hart) is the rural center of the Dutch Randstad, surrounded by the biggest cities in the Netherlands: Amsterdam, The Hague, Rotterdam and Utrecht. The soil of the Green Heart contains mainly sand, peat and clay. The ground water level is controlled in order to avoid fast subsidence due to peat oxidation and at the same time to maintain a dry surface. Peat is composed of organic material which oxides when it is in contact with air, reducing in volume and consequently resulting in subsidence, and therefore, bringing the surface gets closer to the ground water. Thus, in order to have a dry ground suitable for agriculture, construction and recreation the land is periodically drained.

Observing precise subsidence rates of peat and marsh lands using geodetic techniques is notoriously difficult, due to the difficulty of installing fixed benchmarks in this type of soil. Moreover, because of the soft soils, modern buildings have pile foundations, with pilings up to 25 m long, reaching to stable Pleistocene sand layers. Consequently, while subsidence due to shallow surface compaction continues, most new buildings remain relatively stable. Figure 2 shows the subsidence rates estimated by [2] for a ground water level of -40 cm below surface. The results were obtained using boreholes. The area with the maximum deformation rates corresponds to the Krimpenerwaard, where a deformation of -5 to -11 mm/yr is expected.

In this contribution we investigate the use persistent scatterer interferometry, (PSI) [1] to study shallow deformation in wetlands in The Netherlands. PSI utilizes a time series of space borne radar scenes to select scattering objects whose reflecting properties remain fairly constant over time and are therefore minimally affected by noise. The information about deformation is extracted from the interferograms, which contain the phase differences between two radar images.

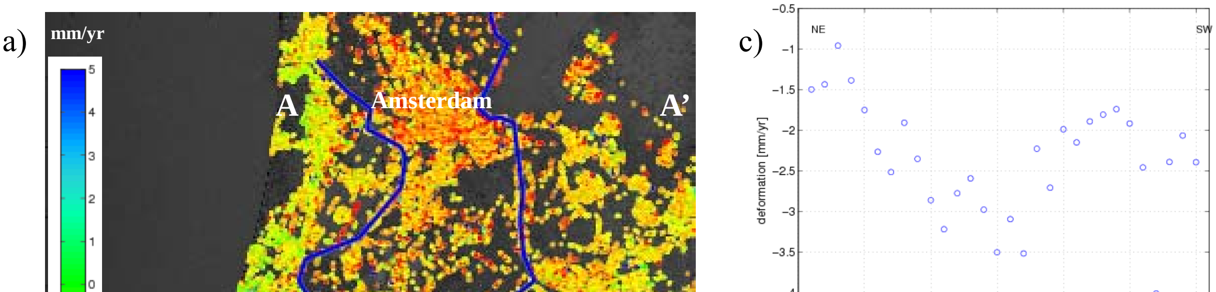
The PSI technique as developed at the TU Delft [3] is based on creating a first-order network of measurements, using the most coherent objects to estimate and remove atmospheric artifacts. Then a denser second order network is built from which the full deformation velocity field is derived.
One of the major limitations of PSI techniques is that we cannot be certain about the object we observed. In any case, the position of the object is known with an error of about 10 m. However, PSI overcomes the limitations of traditional geodetic methods. It provides a very dense distribution of measurements (~ 100/km^2 in urban areas, sensor dependent) and high observation frequency (once a month or higher, depending on satellite requirements).

Figure 2. Location of the processed area.

RESULTS OF THE PSI PROCESSING

We processed 80 radar acquisitions yielding 79 interferograms (phase differences) with respect to a single image, which is usually denoted as master and is, therefore, the time reference. The master image was acquired in August 1998. That means that the deformation on this date is set to zero. The radar data cover the time span from 1993 to 2001. The total processed area is 100x100 km wide.
The estimated rates obtained by PSI are shown in fig. 3a. The area with deformation due to peat compaction is highlighted in blue. The spatial reference is located in The Hague. From fig. 3a, we can see that the peat areas are subsiding with respect to their surroundings. The profiles A-A' , B-B' and C-C' located in the North, center and South of the area show that this displacement ranges from -1 mm/yr to -3 mm/yr on average. It can also be noticed that the profiles are slightly tilted from east to west, which is possibly caused by inaccuracies in satellite orbit parameters.
The most significant differences between the rates estimated by [2] and ours occur in the area of the Krimpenerwaard. This discrepancy is probably produced by the fact that most of the detected radar reflections stem from houses which usually have deep foundations well below the peat layer. However, the similarity between the deformation field we detected and the peat region, suggest a causal relation. The deformation measurements can be explained by two hypotheses or a combination thereof. First, the measurements are obtained by curb-to-walls reflections, being the curb or pavement more sensitive to shallow deformation. Second, in its decomposition process the peat is dragging the house foundations slightly down. Further research is required to further assess these hypotheses.

Figure 4 shows the estimated displacements with respect to The Hague for four scatterers located in Amsterdam, Utrecht, Krimpenerwaard and Delft. The deformation in the first three locations is assumed to be produced by the peat oxidation. As expected the rates in the Krimpenerwaard are the highest. It is also important to remark that the average ground height of these cities is around 2 m NAP, however Krimpenerwaard is situated at -2 and its western part even at -6 m NAP. Therefore, this area required a careful monitoring. Apart from that, the deformation that we detected in Delft is mainly a direct effect of water pumping.
In all four time series a one year periodic signal is superimposed to the overall trend, which is related to seasonal effects such as water loading and/or temperature fluctuations[4].



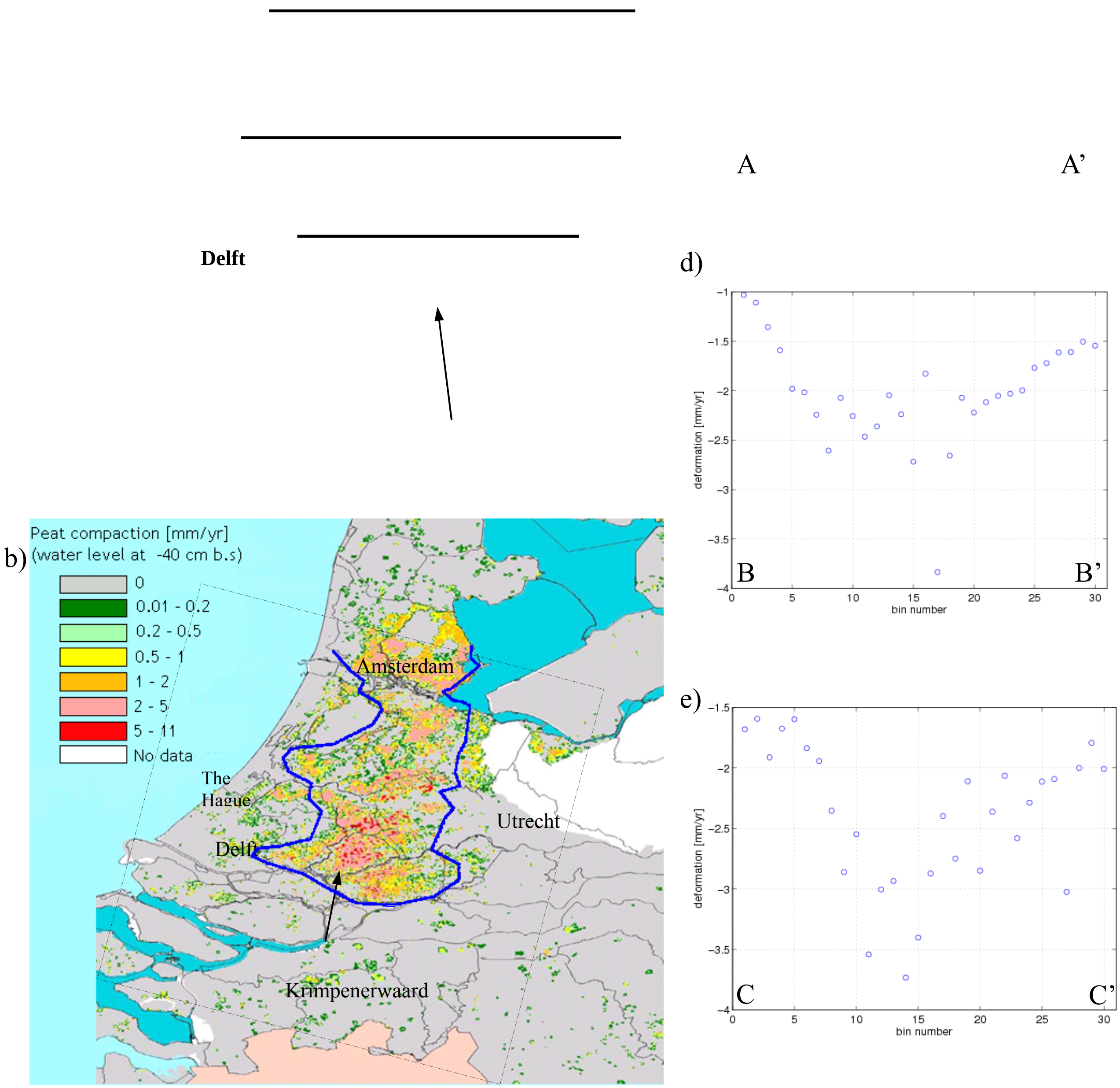
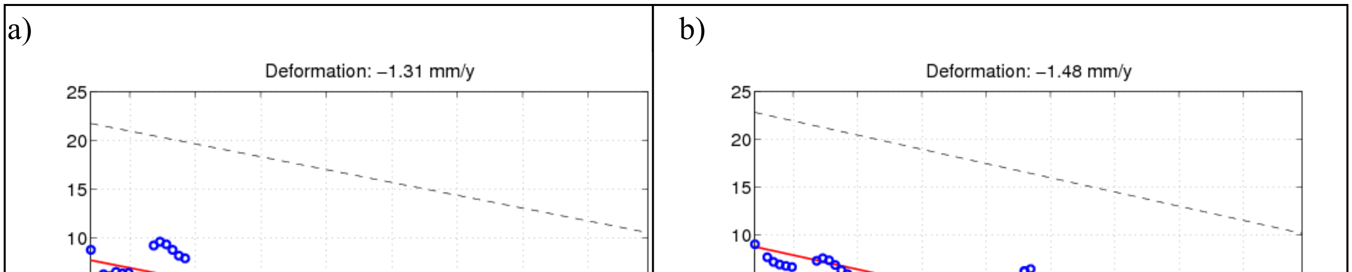


Figure 3. a) The deformation rates in mm/yr estimated by PSI. Some cities have been highlighted. b) Expected deformation due to peat oxidation estimated from boreholes for a ground water table of −40 cm below surface, (after 2 slightly modified). The dashed rectangle represents the area processed by PSI. c), d),e) represents profiles across the deformation field estimated by PSI, located North, center and South in figure a).

SUMMARY AND CONCLUSIONS

After comparing the peat areas and the estimated deformation field we concluded that PSI technique was able to detect motion related to peat oxidation. Thus, we calculated the Green hart to move with rates that range on average from -1 to -3 mm/yr with respect to its surroundings. When studying single point time-series we also found scatterers subsiding at a velocity of -6.4 mm/yr. Finally, the times-series also revealed that superimposed to this motion there is a 1year-periodic signal. This probably related to seasonal fluctuations of the water levels and/or temperature changes.



c) d)

Figure 4 Time-series estimated by PSI for points located in a) Amsterdam, b) Delft, c) Krimpenerwaard and d) Utrecht

REFERENCES

[1] Ferretti, A., C. Prati, and F. Rocca (2001). Permanent scatterers in SAR interferometry. IEEE Transaction on Geoscience and Remote Sensing 39(1), 8– 20.
[2] van der Linden, W., A. H. M. Kremers, and H. J. T. Weerts (2002). Landelijke karakterisatie topsysteem, in opdracht van droogtestudie Nederland RIZA, RIVM en Alterra. Report NITG 02-112-B, TNONITG, Utrecht.
[3] V. B. H. Ketelaar, (2008) Monitoring surface deformation induced by hydrocarbon production using satellite radar interferometry. Ph D. thesis Delft University of Technology, Delft, the Netherlands.
[4] van Leijen, F. and R. Hanssen (2008). Ground water management and its consequences in Delft, the Netherlands as observed by persistent scatterer interferometry. In Fifth International Workshop on ERS/Envisat SAR Interferometry, 'FRINGE07', Frascati, Italy, 26 Nov-30 Nov 2007, pp. 4 pp.