THE APPLICATION OF SAR INTERFEROMETRY TO COASTAL ENVIRONMENTS: A COMPARISON OF INTERFEROMETRIC SOFTWARE

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ABSTRACT

SAR Interferometry is a relatively new microwave remote sensing technique, with many applications in the study of surface topography and in the classification of land surfaces using the coherence parameter. Interferometric signals suffer decorrelation from a variety of sources, including thermal noise, inaccurate registration of the image pair and spatial and temporal decorrelation. Although some of these sources can be avoided or reduced by appropriate data selection, some are clearly attributable to software design. To compare three interferometric software packages, a set of coherence maps of the land surrounding the mouth of the Humber estuary are presented, generated by each different package. The difference in the outputs of the three packages are highlighted, including a numerical contrast, and each are discussed in terms of user-friendliness.

1 INTRODUCTION

This paper reports on the application of the remote sensing technique SAR Interferometry (InSAR) to the study of the coastal zone, and presents contrasting results obtained from different interferometric software packages, discussing each package in terms of user-friendliness and reliability.

The main principle of InSAR relies on the fact that a radar antenna targets the surface with coherent radiation; the backscattered microwave signal follows a sinusoidal wave pattern (Massonet, 1997). SAR imagery is typically used to depict how the varying amplitude of the backscatter can reveal information about the surface geometrical and dielectric properties. The second component - phase - is indicative of the two-way travel path from sensor to target to sensor, the interaction between the incident signal and surface scatterers within the resolution cell and a focussing phase shift induced by the processor (Rocca *et al.* 1997). The phase of one SAR image is therefore uninformative; a second image obtained from a slightly different viewing position is required. By calculating the product of the first with the complex conjugate of a second image accurately registered to the first, an interferogram is formed. Following the process of phase unwrapping, which removes the 2π ambiguity, a Digital Elevation Model (DEM) can be calculated.

As an alternative to the study of surface topography, a coherence map can be generated to investigate surface stability or for mapping purposes. There has been much research in the field of interferometric coherence, or correlation, and its applications such as forestry (Hagberg *et al.* 1995) and agriculture (Wegmüller *et al.* 1995). Coherence mapping of coastal zones is relatively new, however, but there lies a wealth of information in a coherence image of a coastal area due to the wide range of surface types and moisture content (Rowan and Vaughan 1998).

To compare the packages we present coherence maps of Spurn Bight, north of the mouth of the Humber estuary (U.K.), constructed from ERS-1 and -2 tandem images acquired on the 24th and 25th of October 1995 (orbit numbers 22355 and 2682, frame 2529) with a perpendicular baseline component ($B_\perp$) of 95m. This particular image pair may yield more productive results from coherence mapping anyway due to the small magnitude of $B_\perp$; the difference in elevation between any two fringes on the interferogram is $\approx 9330/B_\perp =$ 98m, according to the formula quoted in Rocca *et al.* (1997) and substituting parameters for ERS-1. (A more suitable $B_\perp$ would be one about 3 times the size.)

2 THE STUDY SITE

The 4.5km-long sand and gravel spit that is Spurn Head, located north of the mouth of the Humber estuary, has been formed as the cliffs of Holderness have succumbed to the process of erosion. The spit is covered in lightly vegetated sand dunes and the beaches on the seaward side are known to be highly dynamic, where the sediment is composed of sand and gravel. The 'Binks', a shallow area of sand and gravel banks, is located off the spit tip. Coastal defences along the spit have not been maintained since 1960, however, and have now almost completely failed (Ciavola 1997). To the west of Spurn Head is a massive area of tidal flats, approximately 10km wide, known as Spurn Bight. The sediment of Spurn Bight is composed of clay and silt with the exception of isolated sand patches. Over the backshore, an area of saltmarsh is present (Ciavola 1997).

Spurn Bight is an excellent area for a study of this kind, due to its scale and features. Moreover, the varied geomorphology make it an ideal site for surface mapping and monitoring using the coherence parameter.

3 INTERFEROMETRIC CORRELATION

3.1 Definition

The parameter which determines the quality of the fringes on an interferogram is interferometric correlation, or coherence. It is a measure of the variance in phase noise, and is dependent upon quantities such as the signal-to-noise ratio of the interferometer, various orbital parameters and any changes in the geophysical properties of the surface scatterers. It is a highly useful quantity itself in that it can provide valuable information about changes which have occurred over the timescale of the image pair such as vegetation growth, soil moisture induced effects and permafrost freezing and thawing.

A coherence map is generated from a product of two complex, registered, SAR images. Coherence is represented as a dimensionless variable between 0 and 1, with unstable or uncorrelated surface areas such as the sea surface demonstrating low coherence values.

3.2 Sources of decorrelation

There exist five main sources of coherence loss in interferometric signals (Li and Goldstein 1990, Zebker and Villasenor 1992):

1. Thermal decorrelation, which is a function of the interferometric system signal-to-noise ratio (SNR), and is due to the thermal noise of the interferometer.
2. Speckle, which can be reduced by obtaining averages over multiple pixels or 'multilooks'.
3. Image mis-registration, since one cell is composed of many distributed scatterers registration to the highest accuracy - typically 1/10 of a pixel - is vital.
4. Spatial baseline noise, which is the effect of viewing the scene from two different angles.
5. Temporal decorrelation, the least predictive source, which is due to changes in the geophysical properties of the target or the physical rearrangement of the scatterers between the acquisition of the two images.

These sources combine multiplicatively to form an observable, total, correlation. If effects due to speckle and mis-registration can be minimised, with knowledge of the SNR and orbital parameters the temporal contribution can be evaluated or approximated for different surface types and times periods.

4 INTERFEROMETRIC SOFTWARE: DESIGNED FOR USERS?

Due to the high cost of computer software and the fact that InSAR is still a relatively new area of study, interferometric software would appear to be in rather short supply in research establishments, except where it has been written by the actual research teams themselves. In the case of the University of Dundee, we have been fortunate enough to gain experience of several interferometric software packages, either in the form of temporary licences or by studying results which were processed for us by another group. This situation has allowed us to judge several packages for user-friendliness and reliability, and to compare the outputs of each package.

The three software packages under discussion in this section are:

- *ISAR/AIG*, where *ISAR* was developed for ESA at POLIMI and used in this case by UCL for image co-registration, and *AIG* was developed by POLIMI for interferogram and coherence map generation.
- *PCI-IFSAR*, the programs written as an extension to the well-established image processing package.
- *EarthView InSAR*, developed by Atlantis Scientific Systems and PCI jointly.

We spent two seperate, concentrated, two-month periods becoming familiar with the PCI interferometric programs (hereafter referred to as PCI) and EVInSAR. The coherence maps produced by ISAR/AIG, PCI and EVInSAR are shown in Figures 1, 2 and 3 respectively, in the slant-range projection for clarity.

The first and most obvious point to note is the lack of uniformity in the output of the three packages, which are theoretically performing identical tasks. We discuss each of the three packages in turn.

4.1 ISAR/AIG

Not being a commercially-developed software package, we believe ISAR/AIG was not designed with user-friendliness as a priority. In terms of output, we were presented with an excellent set of results which included Spurn Bight as an amplitude image, interferogram and coherence map in various projections. The coherence map shown in Figure 1 (with an equilizing image enhancement applied), however, displays an systematic error which manifests itself as striping occurring every 50 rows. The calculated values for interferometric correlation appear to take on a false, constant, value for several rows. (This particular image was unusual in displaying this processing artefact.) Application of several types and sizes of filter failed to reduce the striping. On a positive note, it does depict a wide range of coherence values spread over the surrounding land and Spurn Bight, and the whole length of Spurn Head is visible.

4.2 PCI

At first glance, Figure 2 which contains a coherence map generated by PCI (with an equilizing image enhancement applied) appears to be of a higher quality than Figure 1. There exists a bigger contrast between areas such as the inter-tidal zone and the backshore, and the borders of fields are better defined. A serious criticism, however, is that the lower 2km or so of Spurn Head is not visible which would imply a lower registration accuracy compared to ISAR/AIG.

Since the arrangement with PCI was a cost-free temporary licence, there was no user support available to us *e.g.* in the form of a manual. We found that almost half of the demonstration time was lost in learning to use the package. The simple task of creating a coherence map involved running no less than 10 of the 42 available programs in the Interferometry group within Xpace. Although the IFSAR programs are simply listed alphabetically, to complete any particular project they must be executed in strict sequence. It was revealed to us, when we discovered that none of the 6 phase unwrapping programs were actually running, that this package was no longer available for purchase.

Advantages which PCI has over EVInSAR however (see below), are that these images were co-registered using orbital parameters only, and that the package is also capable of handling one complex SAR.SLC scene at a time for generation of an amplitude image only.

4.3 EVInSAR

EVInSAR products such as the coherence map in Figure 3 (with an linear image enhancement applied) initially indicate an improvement once more; a closer inspection reveals this impression is a false one. One can surmise from various qualities of this image (the extra width of the roads and borders of the backshore, the patchiness of the sea and strong scatterers in Grimsby) that it has already had a filter applied to it. By testing the other two coherence maps with different types and sizes of filter, we deduce that EVInSAR has automatically applied an operator such as a 5x5 Median filter to the coherence map.

This package was definitely designed with the user in mind; we were processing data within a couple of days. 'Help' pages describe how the whole program runs interactively, although the intuitive windows set-up ensures that they are there only for extra information. The program lost favour with these users, however, when attempting to register image pairs where only a few man-made Ground Control Points were present. The accurate co-registration involved some time-consuming manual intervention as in the case of the site under discussion - but happened only rarely. Another disadvantage is that the package is only capable of handling *two* complex scenes *together i.e.* even if only the amplitude image of the first scene is all that is required, the image pair still have to be co-registered and interferometric products generated.

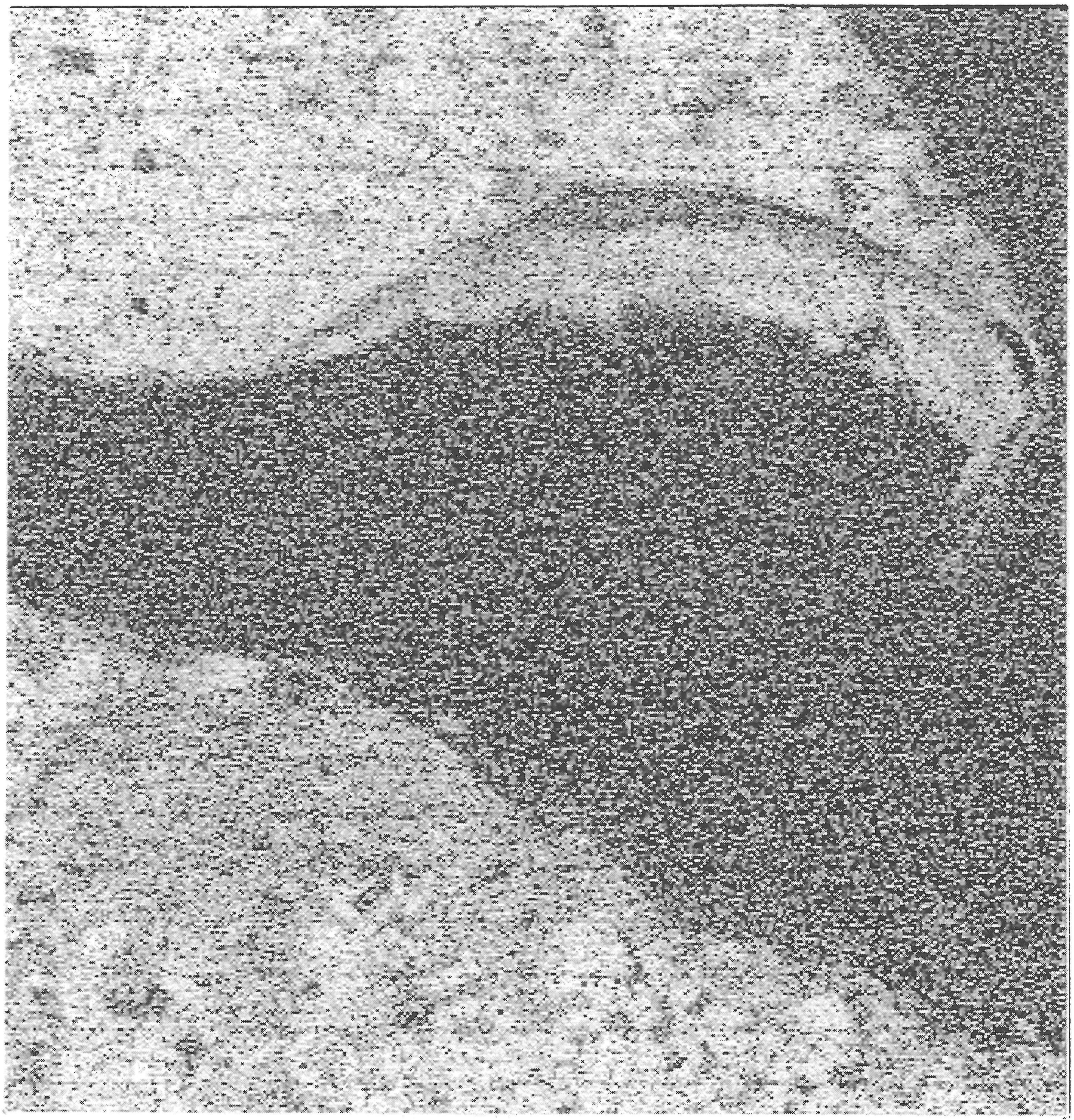

Figure 1: Coherence map of the mouth of the Humber estuary, created using ISAR/AIG.

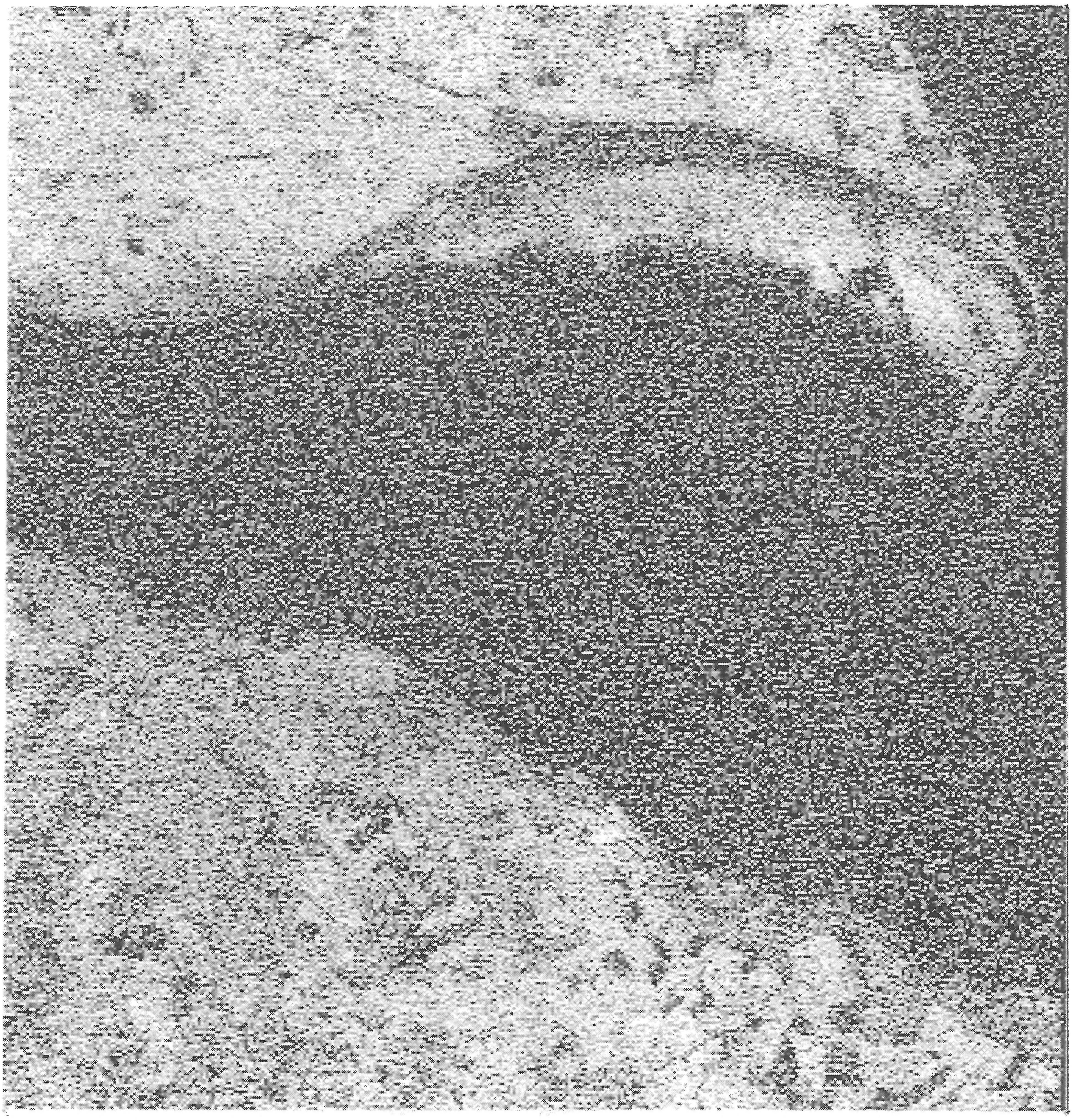

Figure 2: PCI-IFSAR coherence map of the mouth of the Humber estuary.

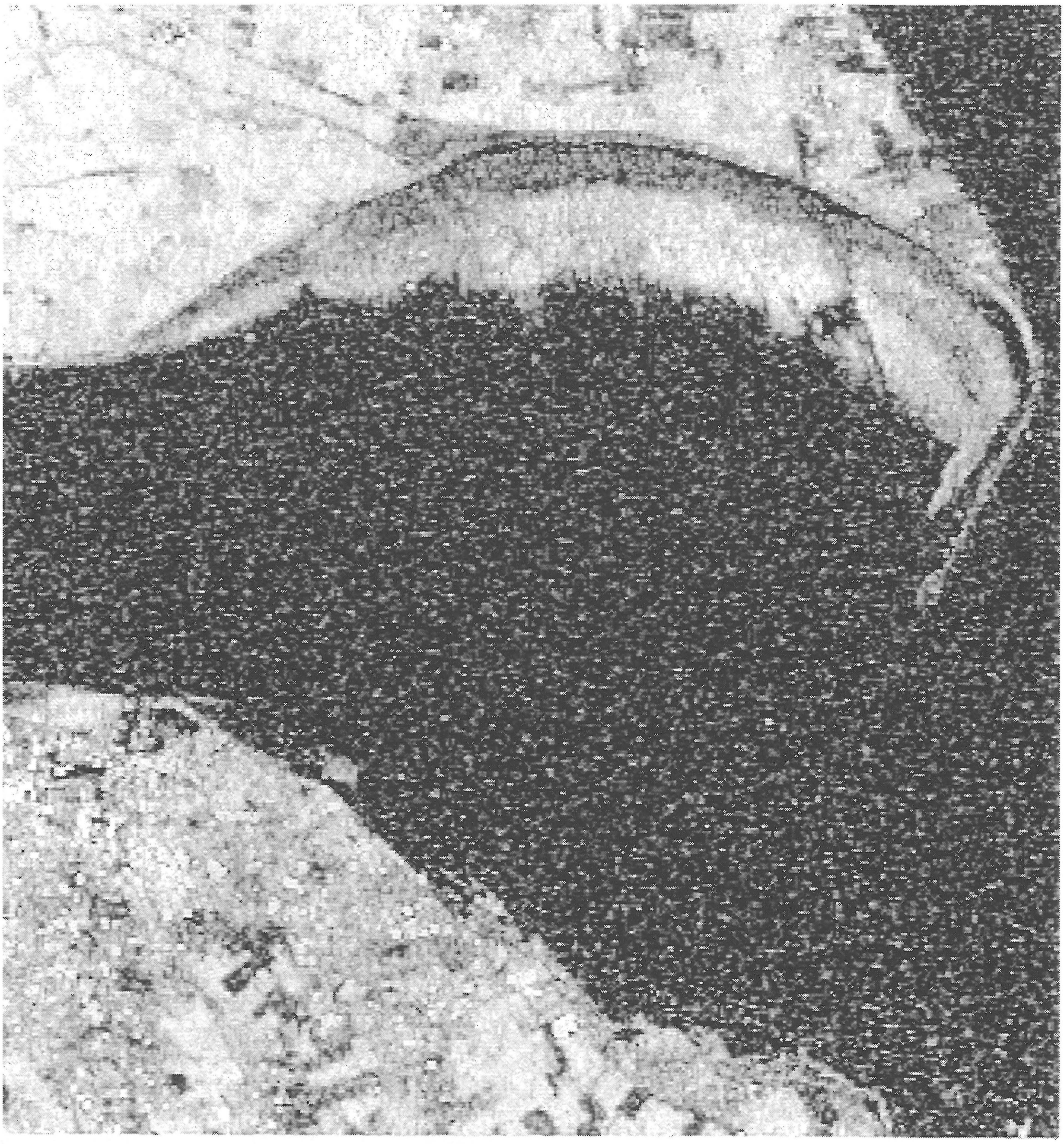

Figure 3: Coherence map of the mouth of the Humber estuary, generated using EarthView InSAR software.

Software Package	Correlation Co-efficient		
	Backshore	Spurn Head	I.T. Zone
ISAR/AIG	0.12	0.24	0.31
PCI	0.31*	0.43	0.61
EVInSAR	0.19	0.37	0.55

Table 1: Average coherence values for a selection of surface types.
(* *This figure was calculated over a smaller area of Spurn Head compared to the other packages, but using the same number of samples.)*

4.4 A numerical contrast

Table 1 contains coherence values (figures were calculated by averaging over a reasonable, $N > 40$, number of pixels) for the three packages based on three surfaces around the coastal zone: along Spurn Head, the highly coherent inter-tidal zone (ITZ) and the backshore which consists of saltmarsh. Although the figures appear to show that PCI provides consistently higher coherence values than the other software packages for every surface, a numerical comparison in this context is invalid for several reasons. Firstly, at the interferogram generation each package will have applied some kind of enhancing filter with the aim of reducing decorrelation. Secondly, the actual method with which the coherence is approximated may vary from one package to another. The final point to note is that coherence values are spatial averages over a window size which is a characteristic of the particular software.

Considering each package seperately, however, the order in which the coherence values lie is not unexpected given the nature of the coastal geomorphology. Vegetated surfaces have been shown to demonstrate lower coherence than non-vegetated (*e.g.* Wegmüller and Werner 1997), which clearly explains why the backshore has the lowest value for all three packages compared to the lightly vegetated spit and sparse ITZ.

5 CONCLUSIONS

It is clear that some sources of decorrelation can be minimised through appropriate data selection although other sources must be attributed to the performance of the software.

Factors contributing to the hugely different outputs include the various filtering mechanisms used in the interferogram generation of the three packages. Indeed, as noted in Section 4.3, a 5x5 Median filter was capable of making the ISAR/AIG coherence map appear very similar to the EVInSAR example. Lack of information about the exact nature of the filters as well as the accuracy of image co-registration make it difficult to compare the packages in terms of capability.

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