Article

SHORELINE DETECTION USING TERRASAR-X QUAD POLARIZATION MODE

By Diego A. GURREONERO ROBINSON, Wietske BIJKER, Valentyn A. TOLPEKIN

University of Twente, Faculty of Geo-information Science and Earth Observation; P.O.Box 217; 7500 AE Enschede; (The Netherlands)

In the Netherlands, the coastal zone is a dynamic area because of the geographic position. Economic activities and effects of global warming demand a frequent, accurate and detailed update of the coastline information. For this study, TerraSAR-X quad polarization was obtained at 6.6 m azimuth resolution during the Dual Receive Antenna (DRA) campaign. The coastline is detected by decomposing the polarimetric SAR components in three different scattering mechanisms: volume scatter, double bounce scatter, and surface scatter. This composite scattering model allows to classify the image based on these different scattering mechanisms. After the decomposition, region growing segmentation is applied to group neighboring pixels with similar values to identify the coastline as the boundary between land and sea. Scheveningen beach has been chosen as case study. The primary methodology is the Freeman and Durden decomposition followed by two classifications (1) Wishart supervised with Maximum Likelihood and without supervised classification and region growing segmentation or (2) with segmentation applied directly to the decomposition results. The output segmentation vector is validated by comparing with nautical charts. After the decomposition and classification of the scatter mechanism, statistics showed good signature separability. The region growing segmentation gives good outputs according to the difference in group pixels related to the land and those related to the sea.

Abstract

Aux Pays-Bas, la bande côtière est une zone dynamique de par sa position géographique. Les activités économiques et les effets du réchauffement climatique requièrent une mise à jour fréquente, précise et détaillée des informations relatives au trait de côte. Dans le cadre de cette étude, des images en polarisation quadruple de TerraSAR-X ont été obtenues avec une résolution en azimut de 6,6 m pendant la campagne « Dual Receive Antenna » (DRA – antenne en mode de réception double). Le trait de côte est détecté par la décomposition des composantes SAR polarimétriques selon trois mécanismes de diffusion : diffusion volumique, diffusion double-bonds, et diffusion surfacique. Ce modèle de diffusion composite permet la classification de l'image à partir de ces différents mécanismes de diffusion. Après la décomposition, la segmentation par approche « région » est appliquée à un groupe de pixels voisins ayant des valeurs similaires pour identifier le trait de côte en tant que frontière entre la terre et la mer. La plage de Scheveningen a été choisie pour une étude de cas. La principale méthode est la décomposition de Freeman et Durden suivie de deux classifications (1) la classification de Wishart, supervisée par maximum de vraisemblance et sans supervision, et la segmentation par approche « région » ou (2) l'application directe de la segmentation aux résultats de la décomposition. Le vecteur de segmentation en sortie est validé par comparaison avec les cartes marines. Après décomposition et classification du mécanisme de diffusion, les statistiques ont montré une séparabilité des signatures satisfaisante. La segmentation par approche « région » donne de bons résultats d'après la différence observée entre les groupes de pixels relatifs à la terre et ceux relatifs à la mer.

Article

Resumen

En los Países Bajos, la zona costera es una zona dinámica a causa de la posición geográfica. Las actividades económicas y los efectos del calentamiento mundial exigen una actualización frecuente, precisa y detallada de la información de la línea de costa. Para este estudio, se obtuvo la polarización cuadrangular TerraSAR-X a una resolución en acimut de 6,6 m durante la campaña DRA (Antena de Doble Recepción). La línea de costa es detectada mediante la descomposición de los componentes polarimétricos SAR en tres mecanismos diferentes de dispersión: dispersión de volumen, dispersión de doble rebote, y dispersión de superficie. Este modelo de dispersión compuesto permite clasificar la imagen basándose en estos mecanismos de dispersión diferentes. Después de la descomposición , la segmentación de crecimiento de regiones se aplica a los píxeles colindantes agrupados con valores similares para identificar la línea de costa como límite entre tierra y mar. Se ha elegido como estudio de caso la playa de Scheveningen. La metodología principal es la descomposición de Freeman y Durden, seguida de dos clasificaciones: (1) la clasificación de Wishart, supervisada por un máximo de probabilidad y la segmentación por enfoque de “región” o (2) la segmentación aplicada directamente a los resultados de la descomposición. El vector de salida de la segmentación se valida mediante la comparación de las cartas náuticas. Tras la descomposición y la clasificación del mecanismo de dispersión, las estadísticas mostraron una buena separabilidad de distintivos. La segmentación por enfoque de “región” proporciona buenos resultados según la diferencia observada entre los grupos de píxeles relativos a la tierra y los relativos al mar.

1. INTRODUCTION

In the Netherlands, the coastal zone is a dynamic area because of the geographic position, natural and human changes. Global warming conditions, conservation of the natural environment and economic activities all demand a continuous and accurate detailed coastline detection. This research explores the possibilities of the new quad polarization mode from TerraSAR-X [1] (***Figure 3***, ***Table 1***) for shoreline detection based on classification of scattering mechanisms and the large backscatter contrast between water and land. The purpose of this study is to detect the shoreline by decomposing the polarimetric SAR components in three different scattering mechanisms, which are; volume scatter, double bounce, and Bragg- or surface scatter. This composite scattering model shows a useful way to classify the image in different classes from the different mechanisms described before.

Up till now, the most common way of coastline mapping is via interpretation of high-resolution aerial photographs, together with field measurements. A number of researchers have investigated the use of SAR for coastline extraction. Maureen et al. [2] investigated polarimetric methods for extracting land-water boundary from airborne SAR imagery. Greidanus and Otten [3] focused on the use of different polarization modes and different incidence angles for sea wave height measurement and determination of coastline and surf-zone. Automated delineation of the land-water boundary from SAR imagery, using filters and speckle reduction was applied by Yu and Acton [4], who obtained acceptable results compared to manual delineation. Baghadi et al. [5] described use of airborne SAR imagery for coastline extraction and concluded that for visual interpretation, both cross-polarization and co-polarization using high incidence angles give acceptable results.

Quad polarization radar data for coastline mapping detection and other applications remains in its nascent stages, as a result of limited availability and evaluation. Moon et al. [6] showed that the composition of tidal flats can be obtained from fully polarimetric AIRSAR data. For the detection of the coastline they combine the AIRSAR data with GPS measurements and hydrodynamic modeling. Arjun et al. [7] shows how combination of SAR quad polarization with Landsat images increases classification accuracy.

The coastal zone varies in width and may also change over time. Several definitions of coastal zone exist, among others by Nelson [8]: "A coastal zone is the interface between land and water". Bird [9] subdivides the coast into several zones.

The coast is divided by the following terms [10]; the shore is the zone between the water's edge at low tide and the coastline; it contains the foreshore, exposed at mean low water level (MLWL) or low tide and hidden or submerged at mean high water level (MHWL) or high tide, and the backshore, extending from the high tide or MHWL and inundated in not normal conditions, like storms or anomaly high tides.

The coastline is defined most of the time as the land margin in the backshore zone. Coastline can be referred as the sea which adjoins the coast, comprising the nearshore and offshore zones, as coastal waters [9].

A Baseline can be defined as a boundary line that determines the beginnings and ends of the sovereignty and jurisdiction of a maritime state. According to UNCLOS, [11] a Baseline can be defined in two aspects; Article 5, Normal Baseline is drawn at the low-water line of a coastal state as marked on large-scale charts officially recognized by the coastal state and Article 7, Straight baseline is when the coastline is deeply concave or if there is a fringe of islands along the coast, the method of straight baselines can be apply by joining the appropriate points from the baseline and the breadth of the territorial sea.

Table 1*: Image information, tide level and related*

Image information	
Image	dt_481_delft / 3
Mode	Quad Polarization
Date	09 / 05 / 2010
Capture time	06 hrs. 08 min 30 sec
Method	2
Tide Level	-77 cm (Tide table)
Distance to Baseline	50 m approx. on the landside from Baseline

2. METHODOLOGY

Quad polarization images from TerraSAR-X are still under experiment. In that sense, we dealt with many difficulties to achieve the objectives. There were not many software packages capable of handling the data. Only one program PolSARpro was able to make this research possible, but it was not fully validated, as shown on their website [12]. The main objective of this research is to evaluate the use of the complete backscattering information coming from the polarimetric data, by using the experimental quad polarization mode from TerraSAR-X, with high spatial resolution as fine as 3 m, to map the shoreline of the South Holland province as the study area. The detection of shoreline from SAR imagery is possible due to the large contrast between backscatter from water and land. For example, if the sea is relatively calm, it acts as a specular reflector; very low backscatter is coming back from the surface and this contrasts well with land that typically has higher backscatter. The shoreline detection can be more difficult due to wind induced surface roughness on the water which reduces the contrast between land and water [13]. Waves and tides also complicate the shoreline extraction due to the change of dry land to wetland and vice versa. For the analysis and decomposition of the polarimetric data, Freeman and Durden decomposition was selected, because it can identify the difference between volume scatter, double bounce, and surface scatter.

Taking advantage of the decomposition and the low backscattering from water, the line between land and sea can be extracted by classification followed by segmentation of the complete polarimetric data. Figure 1 shows the general workflow of this research.

A Refined Lee filter [14] was used to reduce speckle while preserving the polarimetric properties and statistical correlation between channels, avoiding cross talk and image quality degradation. Speckle reduction was a mandatory step to reduce the abundant speckle in the images. The speckle reduction for a single polarization is much easier than for multi-polarization, because the filter should preserve the polarimetric properties and it should deal with the cross-product terms [14]. In that sense, the selection of the appropriate speckle filter for polarimetric data was important. These principles make Refined Lee speckle filter the most appropriate filter for this research. Nevertheless, the filter was tested first, and analyzed by comparing different windows sizes (***see Figure 2***).

Using Freeman decomposition, the polarimetric data was decomposed into three scattering mechanisms: volume scatter, double-bounce, and Bragg- or surface scatter. This technique uses the physically based, three component scattering mechanism model to the polarimetric SAR data without using any ground control point measurements.

The three-component scattering mechanism model is useful to distinguish between different surface cover types and to detect and determine the current state of the surface cover [15].

The georeferencing of TerraSAR-X data in the experimental mode was not possible using the PolSARpro program. The header information from a sample image in the study area already georeferenced by the DLR team, was extracted with the purpose to edit the header of the Classified Wishart image and the Freeman and Durden RGB image with the correct header information. Once the image was georeferenced and after applying the different methods implemented in this research, the raster image in .tif format is exported to ArcMap 10 to do the final georeferencing process. An affine transformation was selected because it is a linear (or first order) transformation and transforms one 2D Cartesian coordinate system to another 2D Cartesian coordinate system. It relates the two 2D Cartesian coordinate systems through a rotation, a scale change in x and y direction, followed by a translation [16]. The affine transformation carries parallel lines into parallel lines. While it preserves proportions on lines, it does not necessarily preserve angles or lengths. During the affine transformation, well detected structures such as harbor, port and the Scheveningen Pier were taken as reference places to take the tie points. More than 10 tie points were acquired to make the affine transformation more accurate, while the minimum number of tie points required for this transformation method is only 3.

For classification based on these scattering mechanisms, two methods were used: The first method applied Supervised Wishart Maximum Likelihood statistics on the Freeman decomposition image, followed by multi-resolution segmentation and classification in eCognition Developer. The second method used the Freeman decomposition image directly as input for multi-resolution segmentation and classification in eCognition Developer. The shoreline was extracted from the classified images.

For the validation process two methods were applied. The first applied buffer detection techniques to compare the extracted shoreline to the Baseline from the Dutch Hydrographic Service. From the reference, four buffers were created from the Baseline towards the land and one more from the Baseline towards the North Sea. Analysis showed how well the output lines coincided with the reference given the tide at the moment that the image was captured. The second validation method used image interpretation and Nautical Charts for comparison.

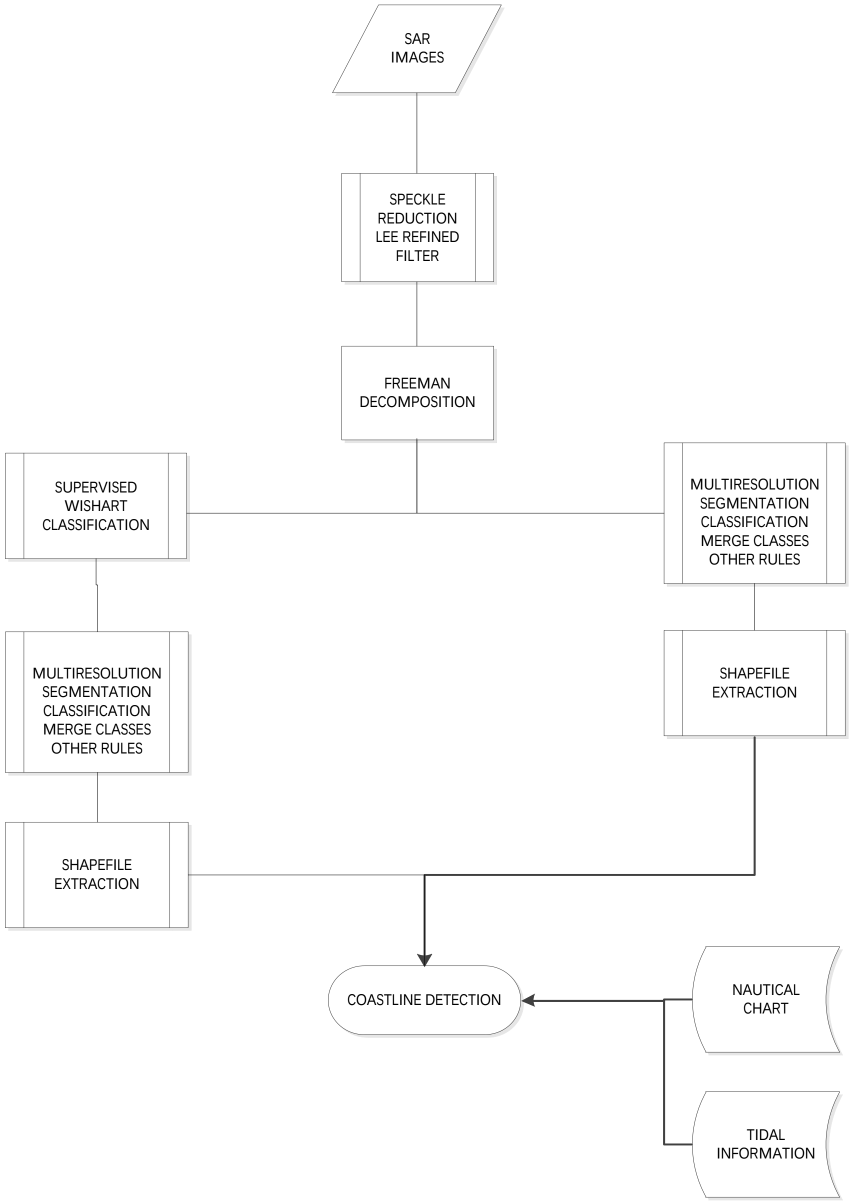
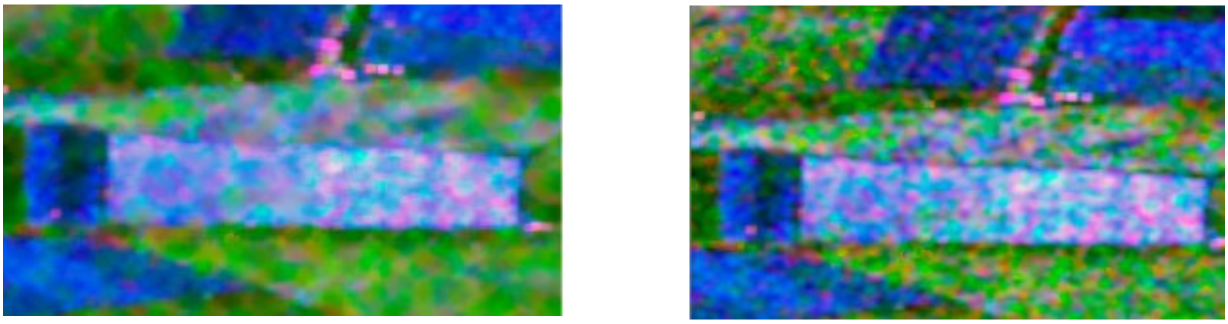


***Figure 1**: General workflow*

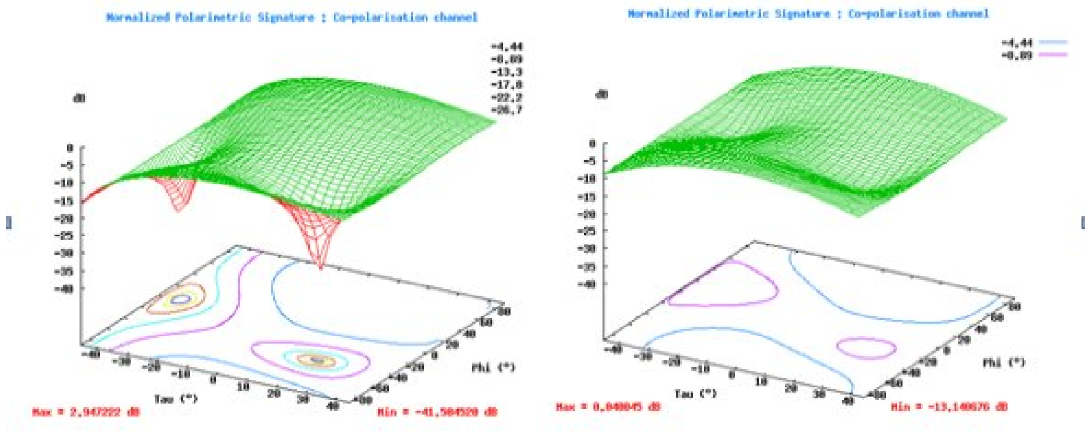
3. RESULTS

Intermediate results, final results and the validation process for the outputs achieved from the six quad polarization images are described. For speckle reduction, ***Figures 3*** and **4** compare the co- and cross polarization signatures, without filter and after applying filter. The Refined Lee filter was tested and the results (***Figure 2***) were analyzed by comparing different window sizes. **Figure 2** compares the Freeman and Durden decomposition (a) Filtered image with 11 x 11 window size and (b) Filtered image with 5 x 5 window size. According to the results, a larger 11 x 11 window size provides more speckle smoothing; a smaller 5 x 5 window filter was selected for better texture preservation. As the purpose of this research is to analyze the shoreline, window size 5 x 5 better preserves the edge between land and water. The following is an example of the data after the application of the filter with window size 5 x 5. Figure 2 shows the tested area and below in Figure 3 and 4, the different signatures.



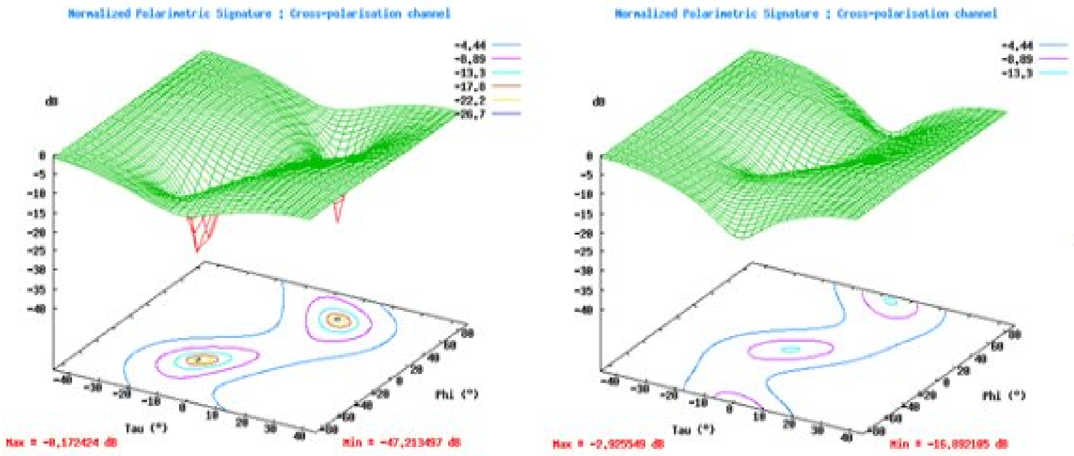
(a) (b)

Figure 2: *Sample area from the Freeman and Durden decomposition output in RGB colors, where Red represents Double bounce, Green represents volume bounce and Blue represents surface bounce. (a) Filtered image with 11×11 window size, (b) Filtered image with 5×5 window size*



(a) (b)

Figure 3*: (a) Original co-polarization signature. (b) Filtered co-polarization signature. Preservation of polarimetric properties is illustrated using co-polarization signatures. The contour plots are similar, indicating the preservation of polarimetric properties, but loosing information at the moment to reduce speckle in the image. The sample point was collected in the land near the shoreline*

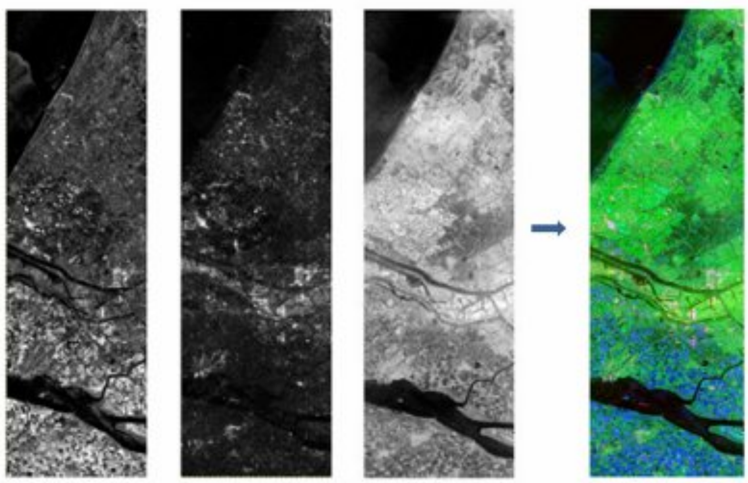


(a) (b)

Figure 4: *Comparison of cross-polarization signatures. The original cross-polarization signature (a) and cross polarization (b) agrees well, but loosing again some information after the filter.*

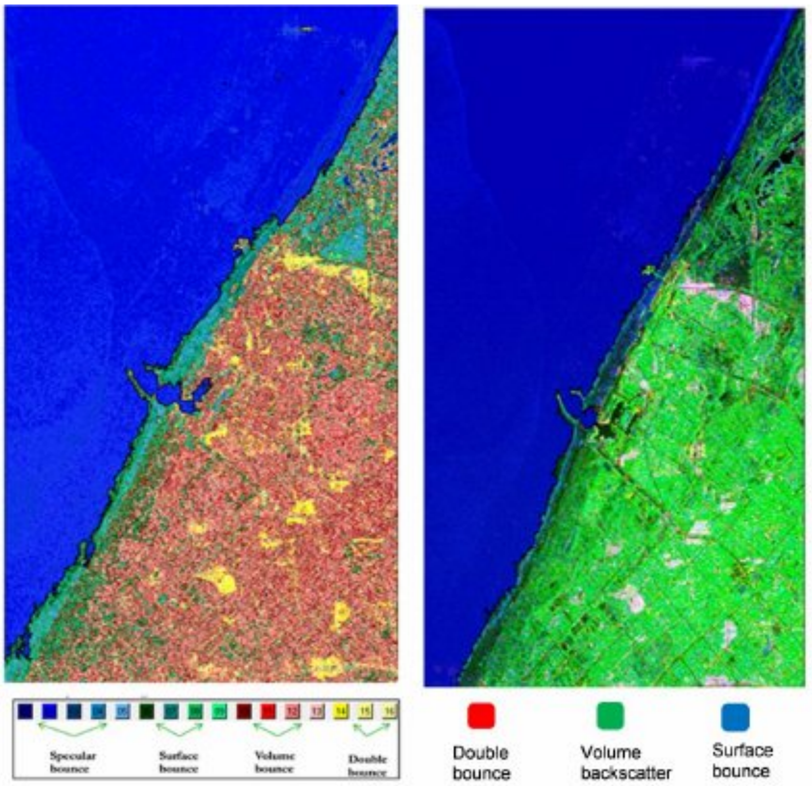
In both ***Figures 3*** and ***4***, the images are preserving the signature and the texture still similar to each other. At the moment that the filter is reducing the speckle, there is a loss of information. That can be important for the analysis On the other hand, the image is a much better input for the segmentation and classification processes.

Figure 5 shows the three Freeman and Durden decomposition [17] layers in surface scatter (a), double bounce (b) and volume scatter (c) Visual comparison of the decomposition with reality shows that different scattering mechanisms are related to different types of land cover. The surface scatter (a) identifies the agriculture area and smooth land, which are shown in high values. Double bounce (b) has good performance to identify the building areas, in more detail, the areas near the harbor, also shown in high values. Finally, volume scatter (c) where the high values appear almost in all the north area of the image, and identifies all the irregular building shapes (urban areas) and some trees, bushes inside the urban parks. ***Figure 6*** shows the results of the two methodologies applied in this research.



(a) (b) (c) (d)

Figure 5*: Freeman decomposition into three backscatter mechanisms: (a)surface scatter, (b) double bounce and (c) volume scatter. (d) Combined representation with double bounce in red, volume scatter in green and surface scatter in blue*.



(a) (b)

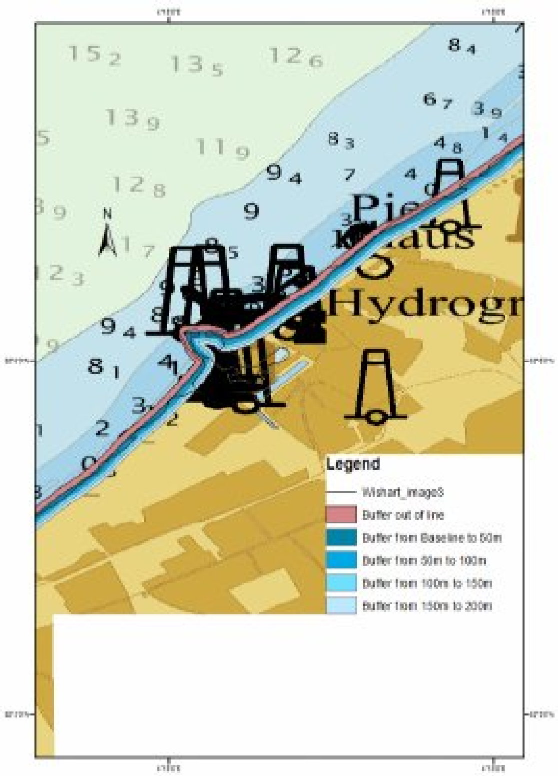
Figure 6: *(a) Result of multi-resolution segmentation and classification after Wishart classification; (b) Result of multi-resolution segmentation and classification.*

For validation, the idea is to evaluate whether extracted shorelines are properly located after the application of both methodologies. From this evaluation it seemed that neither Method 1 nor Method 2 produced accurate results. This does not mean that it was a bad application or procedure during the implementation of these methodologies. External inconvenience mentioned before, affected the good application and results from those methods.

For visual interpretation, the detected shoreline showed good location in comparison to the medium scale nautical chart and with the help of Google Earth program. For the large scale nautical chart, the comparison with the output line was not appropriate because it was not coinciding with the real location of the coastline.

A Buffer method was applied to compare the extracted shoreline to the Baseline from the Netherlands Hydrographic Service. From the reference, four buffers were created from the Baseline towards the land and one more from the Baseline towards the North Sea (see Figure 7). The criteria of this method are to analyze how well the lines detected coincide with the different buffers and in accordance with the current tide at the moment that the image was captured.

Using the Nautical charts from the Netherlands Hydrographic Service [18] as reference data. The output line was inserted on the nautical chart and evaluated in three different scales being 1:250 000, 1:100 000 and 1:50 000. In this paper, the 1:250 000 scale is shown as example. The idea of this evaluation is to determine if the output lines coincide with the map and how useful this can be for the different kinds of purposes. A small scale chart at 1:250 000 can be used just for general information where the precision of the shoreline is not very important. For visual interpretation, the detected shoreline was showing good location in comparison with the nautical chart.



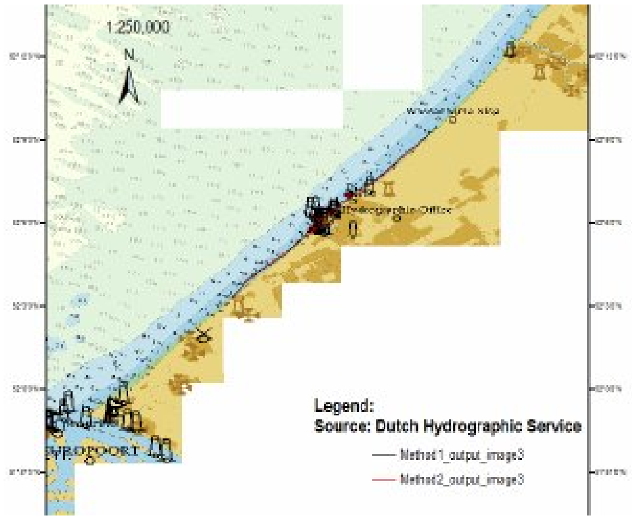


***Figure 7**: Final output for validation and analysis (left) and Nautical chart, original scale 1:250 000 (right)*

4. DISCUSSION

This research explored the new capabilities of TerraSAR-X in quad polarization in a specific application, namely shoreline detection. The results show how well the polarimetric data can be decomposed, classified, segmented and finally exported, to extract the expected shoreline as a shape file by applying Freeman and Durden decomposition and Wishart supervised classification. The use of quad polarization with high spatial resolution satisfies the expectations.

The Freeman-Durden model-fitting approach has the advantage that it is based on the physics of radar scattering. The three component scattering mechanism model proved to be useful in providing features for distinguishing between surface cover types and in helping to determine the current state of the surface cover.

Wishart supervised classification was selected because of the good performance shown in some scientific papers and books and because of the good results when classifying the Freeman and Durden decomposition image.

The presence of speckle in the image made the classification more difficult and the results were not as good as expected. Because of that, the multi-resolution segmentation with region growing technique was having difficulties to merge groups of pixels with the same value. The classification, after the segmentation method on the beach area was more difficult. The differences between sand and water were detected after the classification, but not accurate enough for a good shoreline extraction.

Polarimetric applications in quad polarization mode is still a new topic, on which few scientific papers have been written and even during the recent 4th DLR science meeting, there were not yet sufficient investigation results of this mode. During the implementation of this study, processing quad polarization data resulted to be a complicated and sometimes time consuming process because of the experimental nature of the data, but its implementation in a new application, like shoreline detection, was having good results even without applying many tools.

5. CONCLUSION AND RECOMMENDATIONS

The main conclusion is that the experimental quad polarization image with high spatial resolution as fine as 3m is suitable for the detection of the shoreline in the South Holland province. Accuracy could not be fully evaluated yet because of software limitations, incomplete validation data and the influence of the tide on the horizontal movement of the shoreline could not be properly included.

Speckle reduction was a mandatory step. Some filters for polarimetric data were revised and tested. After some comparisons, Lee Refined filter was selected because, it avoids cross talk and it does not affect the image resolution. Nevertheless, Lee in 2009, proposed a new and improved version of the Lee sigma filter [19].

For classification, Wishart supervised classification demonstrates to have a good performance without needing any ground control point data.

The Dual Receive Antenna campaign is having good results from the scientific point of view, despite some disadvantages, like the availability of the data (just in special campaigns) or the complex configuration, which may not be an impediment to work with it.

It is expected that in the course of new studies, applications and methods using quad polarization images, software developers and researchers will eventually be able to achieve all the ideas and objectives of this study.

Before the selection of the polarimetric decomposition theorem, is very important to first evaluate the purpose and the study area.

Finally, this research can be improved by the use of DTM. The possibility to create DEM with polarimetry data could be developed for this purpose. Accurate tide information can be obtained from the Rijkswaterstaat [20].

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BIOGRAPHIES OF AUTHORS

Lieutenant Diego Gurreonero Robinson is a Naval Officer from de Peruvian Navy. In 2005 he obtained his Bachelor Degree in Maritime Sciences as Hydrographer. Also has served on several warships and Hydrographic ships of the Peruvian Navy (BAP Villavicencio, AEH-174 and BAP Carrasco). In 2010 he obtained his Master of Science Degree from the ITC – The Netherlands. At present is serving at the Peruvian Hydrographic Office as head of the Geomatics Department.
diego_gurreonero@hotmail.com

Dr. ir. Wietske Bijker is an assistant professor of the Department of Earth Observation Sciences (EOS) of the Faculty of Geo-information Science and Earth Observation (ITC), University of Twente, The Netherlands. She specializes in change detection and monitoring based on remote sensing. Uncertainties in change detection, including vague objects and gradual changes are her special interest. She is part of the management team of the department and is responsible for the acquisition of capacity development projects.

Wietske has an MSc in soil science from Wageningen University (1990), where she also obtained her PhD on a dissertation titled: "Radar for rain forest: A monitoring system for land cover change in the Colombian Amazon" (1997). Since 1990 she has been employed at ITC - first as a researcher, later as an assistant professor for the Division of Agriculture, Conservation and Environment and since 2002 for the EOS Department.
w.bijker@utwente.nl

Dr. Valentyn A. Tolpekin received The M.Sc. degree in Physics from Odessa State University, Odessa, Ukraine, in 1997 and the M.Sc. degree in Computer Science from South Ukrainian Pedagogical University, Odessa, in 1998. He holds the Ph.D. degree in Physics from the University of Twente, Twente, The Netherlands. He is currently an Assistant Professor with the Department of Earth Observation Science, Faculty of Geo-Information Science and Earth Observation of the University of Twente, Enschede, The Netherlands. His research interests include image analysis and remote sensing.
v.a.tolpekin@utwente.nl

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