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POLARIMETRIC SAR DATA ANALYSIS FOR IDENTIFICATION AND CHARACTERIZATION OF SHIPS

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ABSTRACT

As part of maritime applications, there is a requirement to detect ships in satellite-borne Synthetic Aperture Radar (SAR) images, which provide all time and all weather wide area ocean applications. Conventional SAR systems operate within a single, fixed-polarization antenna for both transmission and reception of radio frequency signals. In this way a single radar reflectivity is measured, for a specific transmit and receive polarization combination. As a result of this, additional information about the scattering process contained in the polarization properties of the scattered signal is lost. On the other hand, a quadrature polarization radar transmits two orthogonal polarizations namely Horizontal (H) and Vertical (V) and receive the backscattered wave on co and cross polarizations resulting in 4 received channels namely HH, HV, VH, VV. The measured signals in these 4 channels represent all information needed to measure the polarimetric scattering properties of the object which in turn aid in identification and characterization of objects with respect to location and type of scattering mechanism which is otherwise not possible with amplitude only image. This paper presents the analysis carried out using the Radarsat-2 fully polarimetric data for the detection and characterization of ships. Various coherent and incoherent parameters representing the scattering information have been derived. Different decomposition methods were applied to characterize the targets of interest in terms of their elemental scatterers. Each method provides different information about the target. Polarimetric signatures were derived to elicit the scattering mechanisms such as even bounce, odd bounce that would assist in characterizing the typical polarimetric content to characterize the ship. It is observed that Polarimetric SAR can be used to improve ship detection and can provide some additional classification information.

1.0 Introduction

Electromagnetic waves are transverse in nature and therefore have an additional property of the direction of oscillations viz., top, down, left, right etc in a direction perpendicular to the direction of movement. This additional property is called polarization. It is observed that waves of fixed frequency at a fixed location take the form of simple geometric shapes like lines, ellipses and circles. Every feature on the ground scatters radar energy in a certain way. Scattering mechanism characterizes the scattering from a given feature in terms of simple elements for which we know the

the target. The radar system records part of the scattered wave that is directed back towards the receiving antenna. By controlling the polarization of the incident wave and measuring the full polarization of the backscattered wave, the radar system can be used to learn more about the target. Conventional SAR systems transmit one polarization and receive one polarization. Polarimetric radars measure more than one channel while fully polarimetric or quadpol radars transmit with 2 orthogonal polarisations H and V and receive the backscattered wave H and V. The horizontal and vertical waves are transmitted independently on alternate pulses with very short time delay such that waves can be considered to be backscattered from exactly the same part of the surface being observed. This results in 4 channels ie VV, HV, VV and VH where both amplitude and relative phase are measured. Polarimetric SAR is a very powerful tool for extraction of information for identification and classification of different natural features, as each polarization is sensitive to different surface characteristics and properties. With the availability of quadpol data from Radarsat-2 and planned ISRO's RISAT-1 data, opportunities for utilization of polarimetric data will be enhanced. Therefore, utility of polarimetric data for identification and classification of manmade targets is taken up for study. Very few studies are conducted so far to understand the polarimetric response of manmade targets and exploitation of polarimetric parameters for classifying man made targets [1]. Polarimetric SAR data has applications in many areas and several studies were carried out earlier on the use of Polarimetric data for land cover identification [2, 3], urban area identification [4] etc. Many studies have been done to develop algorithms to detect ships in single channel SAR images automatically, where the amplitude information is used to detect ships [5,6]. However, it was observed that amplitude information is not enough to eliminate false alarms caused by speckle and other ambiguities and insufficient to characterize and classify a ship. Thereafter, studies have been reported on the use of 4 channel PolSAR data for ship detection where scattering mechanisms of azimuth ambiguities for polarimetric SAR images were analysed using eigen value, eigen vector decomposition to differentiate ship targets, azimuth ambiguities and sea clutter [7]. Other methods included using a threshold with Constant False Alarm Rate (CFAR) and optimal VV/HH ratio and Polarisation Orientation Angle based analysis [8].

In this paper, an attempt is made to carry out an analysis of SAR Polarimetric data to compute and analyze the polarimetric properties and further use them for identification and characterization of ships. From the input slant range product of a fully polarimetric data set, various target descriptors like Coherency and Covariance matrices were computed from which polarimetric parameters like entropy, alpha, anisotropy etc. were derived. In this work, the polarimetric signature of interaction of the metallic structure of the ship with water is clearly demarcated for the first time through a particular scattering mechanism representing a dipole scatterer. All the ships are found to have similar scattering characteristics. The ellipticity of the detected feature along with the scattering mechanism was used to confirm as ships on the polarimetric data sets.

Section 2.0 provides a brief overview of the polarimetric parameters. In section 3.0 different polarimetric decomposition methods are discussed with emphasis on the Eigen value, eigen vector based Wishart classification. The details of the sample dataset and software used along with a flow chart illustrating the steps followed for automatic ship detection and derivation of additional information are presented in section 4.0. In section 5.0, the results of the analysis are presented and discussed. Concluding remarks with scope for future work are indicated in section 6.0.

2.0 Polarimetric Parameters

Polarimetric data analysis is carried out to compute and derive a number of polarimetric parameters which have a useful physical interpretation. These parameters represent and bring out the scattering properties of the various features on the ground. These parameters are computed for every sample in a polarimetric radar image which can be used for further analysis:

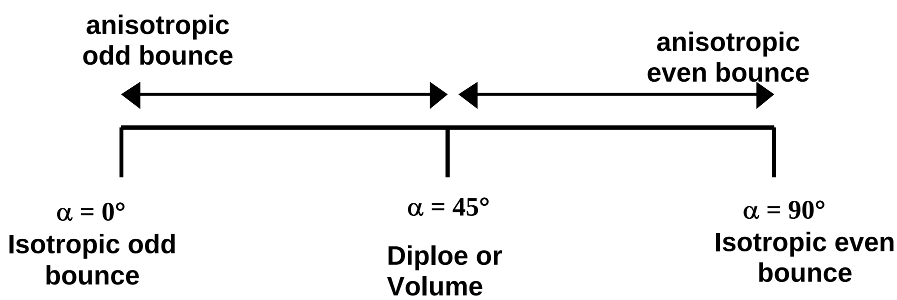
Eigen analysis: The three eigen values of the 3x3 Coherency matrix λ_i represent the intensities of the three main scattering mechanisms. The three eigen vectors represent three main scattering mechanisms present in the sample. The associated eigen values represent the relative strength of that scattering mechanism.

Entropy: Entropy represents randomness of scattering and is computed using equation-1. This is a measure of the dominance of a given scattering mechanism within a resolution cell. Entropy ranges from 0 to 1, where the randomness of a scattering medium from isotropic scattering (H=0) to totally random scattering (H=1). Values in between indicate the degree of dominance of one particular scatterer.

$$H = \sum_{i=1}^{3} -P_i \log_3(P_i) \quad \text{Where,} \quad P_i = \frac{\lambda_i}{\sum_{j=1}^{3} \lambda_j} \qquad (1)$$

Alpha angle:

If the Entropy is close to 0, the alpha angle provides the nature or type of the dominant scattering mechanism for that resolution cell. For example it will identify if the scattering is volume, surface or double bounce. Alpha is calculated based on equation (2).



$$a = \frac{\lambda_1}{\sum_{j=1}^{3} \lambda_j} \cos^{-1}(v^1_1) + \frac{\lambda_2}{\sum_{j=1}^{3} \lambda_j} \cos^{-1}(v^1_2) + \frac{\lambda_3}{\sum_{j=1}^{3} \lambda_j} \cos^{-1}(v^1_3) \qquad (2)$$

Anisot

This is $0 \leq \propto \leq 90$ degrees, where v^1_i is thhe first element of i^{th} eigen vector k direction. A as represented in equation (3), indicates the distribution of the two less significant eigen values. Anisotropy becomes 0 if both scattering mechanisms are of an equal proportion while values of A> 0 indicates increasing amount of anisotropic scattering.

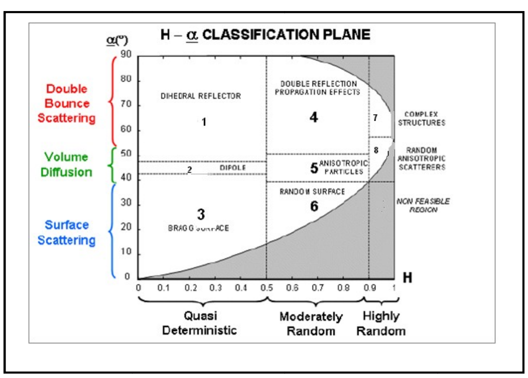
$$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}, \qquad 0 \leq A \leq 1 \qquad (3)$$

3.0 Polarimetric Decomposition and Classification

Target decomposition methods enable analysis of received scattering matrix, to separate and identify contributions from different types of individual scattering components having meaningful physical interpretation in the imaged terrain. Target decomposition methods are of two main categories, coherent and non-coherent. In the coherent case, a single scatterer that produces a fully polarized scattered wave is assumed, and the scattering matrix from a single sample is analyzed. Scattering matrix is decomposed into sub-matrices so that Individual components have physical meaning => Surface scatterer, double bounce, volume scattering. Three methods employed to characterize coherent scatterers based on scattering matrix are: Pauli decomposition, Krogager Decomposition and Cameron decomposition.

Non-coherent target decomposition methods involve analysis of the power forms of the scattering matrix, such as the Mueller and coherency matrices. One of the first such methods has been proposed by van Zyl [12], who classified pixels as odd-bounce, even-bounce or diffuse scatterers. Another method was introduced by Freeman and Durden [13], who decomposed each pixel into Bragg scatter, double bounce and random canopy scatterers. The method defined by Cloude and Pottiere based on eigen values and eigen vectors of coherency matrix gained popularity as it covers the whole range of scattering mechanisms [9]. Different decomposition techniques are applied on the ships to evaluate and characterize them, and this paper presents the results of the Cloude and Pottiere decomposition and H- a classification for identification and characterization of ships.

Several classification techniques like neural network based, object based fuzzy classification [10], comparison of different algorithms [11] have been reported earlier for different applications. In this paper, focus is on the Wishart classification which is done using the non-coherent decomposition proposed by Cloude and Pottiere. The basic scattering mechanism of each pixel of the polarimetric SAR image is identified by comparing its entropy and alpha parameters to fixed thresholds. The different class boundaries in the H- a plane proposed by Wishart, are determined so as to discriminate surface reflection, volume diffusion and double bounce reflection along the x-axis and low, medium and high degree of randomness along the entropy axis. The entropy-alpha space divides the target response into 8 classes in accordance to scattering process and randomness of scattering process as shown in Figure 1. Anisotropy parameter further allows to distinguish different clusters where centres belong to same H- a partition. The third parameter Anisotropy, introduces 16 classes [14,15]



Class	Description	Criteria
	Low entropy scattering (double bounce scattering)	alpha > 48 and H < 0.5
	Low entropy dipole scattering	42 < Alpha <= 48 and H <= 0.5
	Low entropy surface scattering	Alpha <= 42 and H <=0.5
	Medium entropy multiple scattering	Alpha >=50 and 0.5 < H <= 0.9
	Medium entropy dipole scattering	40 < Alpha < 50 and 0.5 < H < 0.9
	Medium entropy surface scattering	Alpha <= 40 and 0.5 < H <= 0.9
	High entropy Double bounce scattering	Alpha > 55 and H > 0.9
	Multiple scattering in high entropy environment	40< Alpha <=55 and H >0.9

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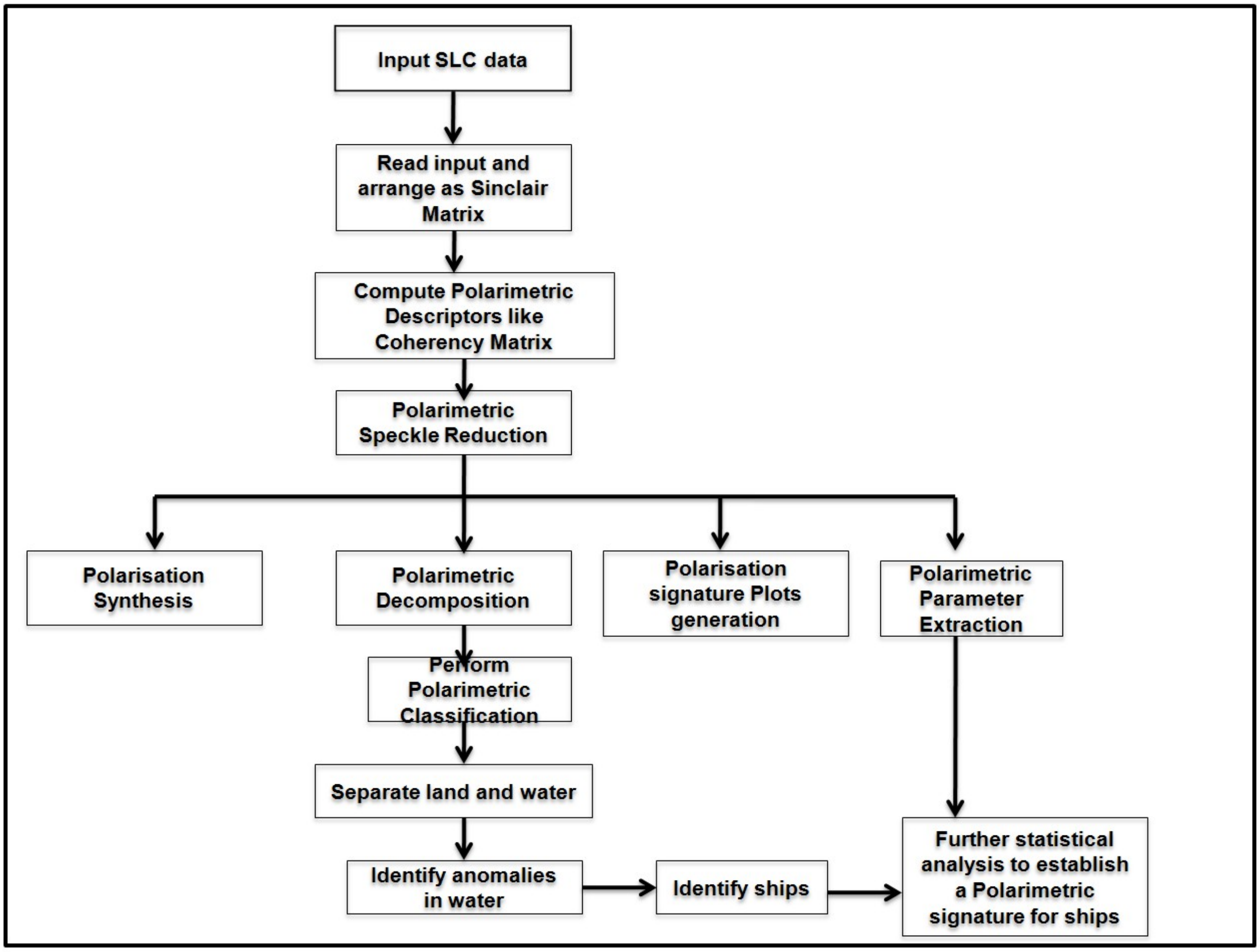
Figure 1: Graph showing Wishart classification with class descriptions

4.0 Materials and Methods Used:

Radarsat-2 image with Fine Quad Polarization and Single Look Complex type obtained on 22nd February 2009 was used in this study. The image has a full polarization of HH, HV, VH, VV, a (range X azimuth) resolution of 8m x 12m, an incidence angle range of 20 – 41 degrees and a swath of 25km.

A Polarimetric SAR data processing and educational tool from European Space Agency along with other image processing tools were used in this work.

From the input SLC data set, polarimetric descriptors like covariance and coherency matrices were derived followed by speckle reduction with Gamma Map filter. Polarimetric parameters were computed followed by decomposition and classification. We adopted the method of land water separation to reduce the search area. The anomalies were detected by CFAR techniques and morphological operations were used to close the objects. It is found that all the ships exhibit a particular scattering



mechanism along the water and metallic ship boundaries. This was again reconfirmed with the shape descriptors like the ratio of length and width of the ship. Having identified as ships, every pixel was subject to polarimetric signature evaluation. Ships were mostly found to have multiple and isolated double bounce scattering indicating the presence of a metallic structure. The position of the metallic structure in the hull may indicate the type of ship. The data flow diagram for the work carried out is illustrated in Figure 2.

5.0 Results and Discussion

An eigen decomposition of the coherency matrix of the fully polarimetric SLC data set was performed. Polarimetric parameters namely entropy, anisotropy and alpha angle are calculated from the eigen values and eigen vectors of the 3 x3 hermitian coherence matrix. These three parameters are independent of rotation of the target about the radar line-of-sight implying that the parameters can be computed independent of the polarization basis. The results of the classification, and identification of ship along with the polarimetric signatures are illustrated in this section.

H-a Decomposition and Wishart Classification results for ship

Wishart classification based on the computed parameters is done and Figure 3 illustrates the classified image, with eight classes (as described in Figure 1) corresponding to low medium and high ranges of entropy and alpha defining different scattering mechanisms. The class in red indicates 'Low entropy surface scattering' corresponding to water. Based on this the land and water classes are separated out for narrowing down the search area and further identification of ships

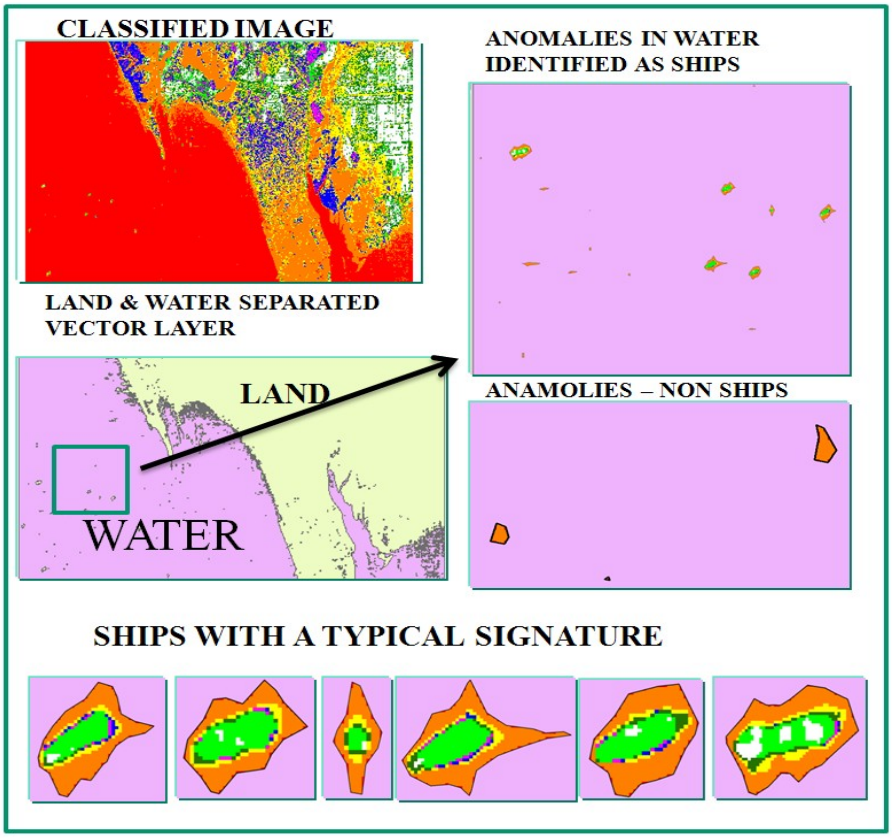


Figure 3: Classified image with water & ships delineated

Automatic Identification of ships

Anomalies within the water are separated and ships are found to show a typical combination of classes as shown in Figure 4. The main observations show that the outer class in the ship indicated in orange corresponds to medium entropy surface scattering which may be due to turbulence in water around the ship. The boundary between water and the metallic body of the ship is characterized as medium entropy dipole scattering shown in yellow color. Within this yellow class is the class of medium entropy multiple scattering shown in green color which is the most dominating class within the ship. This may be due

Figure 4: Classes defining a ship

to the ship structure and a result of multiple bounces from the ship structure. Within this class, there are specific areas falling under low entropy double bounce scattering

indicating the presence of objects causing strong double bounce scattering. This is additional information which could be derived from quad-polarisation data over single polarization data. This information along with the size of the ship would aid in narrowing down the type of ship under consideration.

The H- **a** decomposition results of different ships where each pixel is assigned to one of the eight classes, along with histograms indicating the distribution of different classes within each ship are shown in figure 5. As might be expected, the ship image predominantly includes small areas of double bounce scattering in the centre, majority of pixels in multiple scattering from the main body of the ship and dipole scattering at the water ship boundary line. The outer class indicated in orange corresponds to medium entropy surface scattering which may be due to turbulence in water around the ship. Table 1 illustrates the percentage of pixels falling in each of the eight classes (except class 6 as it is outside the ship) for 4 sample ships considered.

Table 1: Percentage of pixels in each class for 4 sample ships

Class / Ship	1	2	3	4	5	6	7	8
1	3	9	5	60	21	-	4	1
2	4	5	8	50	21	-	6	7
3	2	8	5	56	18	-	56	5
4	4	12	6	56	15	-	4	4

Approximate dimensions including length and breadth of the ships in terms of slant range pixels are shown in Table 2. The observed dimensions of the samples also confirm that the objects of interest could be ships.

Table 2: Dimensions of ship samples in number of slant range pixels

Ship Sample	Length in slant range pixels	Breadth in slant range pixels	Ratio of length and breadth
Ship1	30	16	1.875
Ship2	12	6	2
Ship3	24	12	2
Ship4	24	13	1.846
Ship5	36	16	2.25
Ship6	30	14	2.14

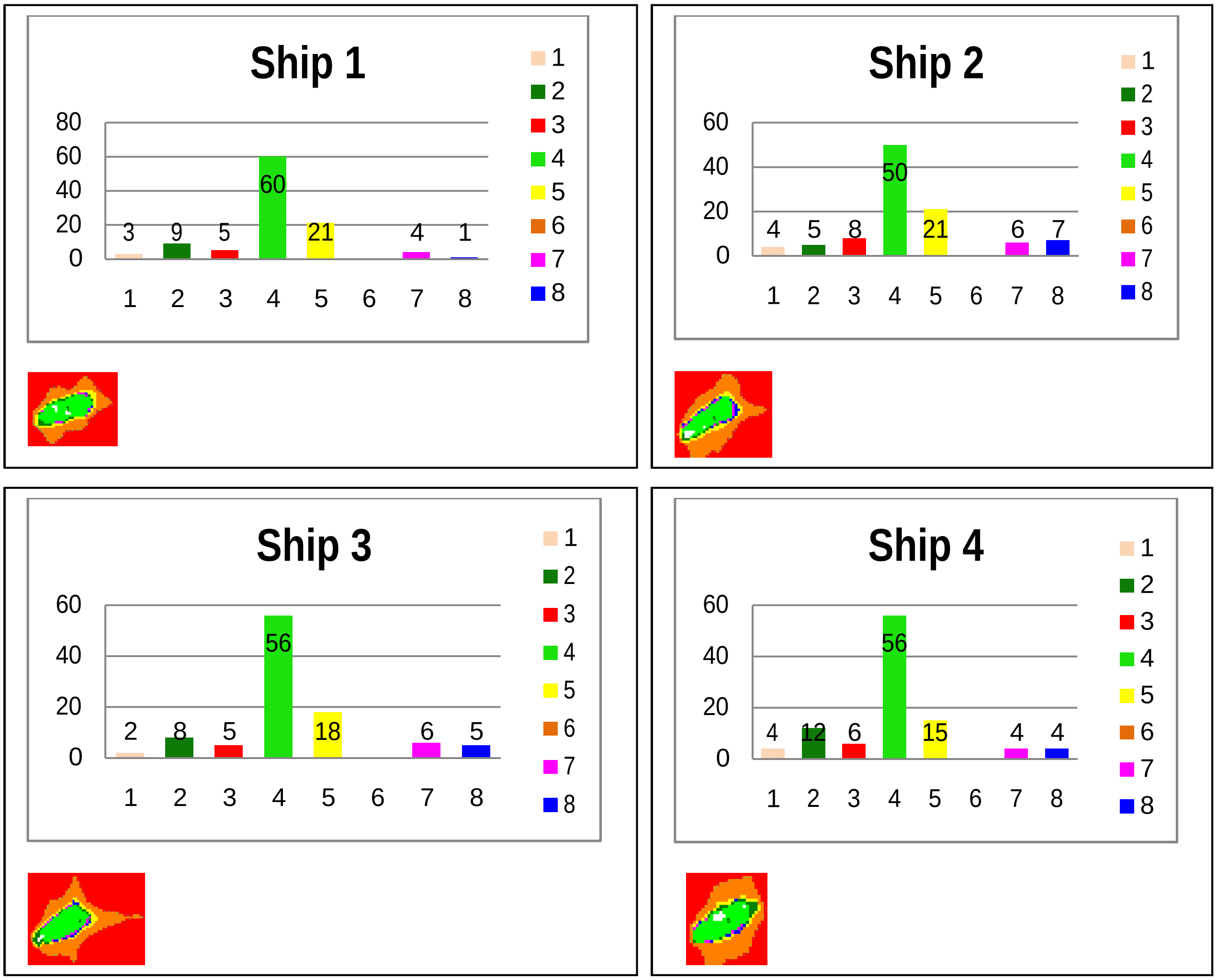
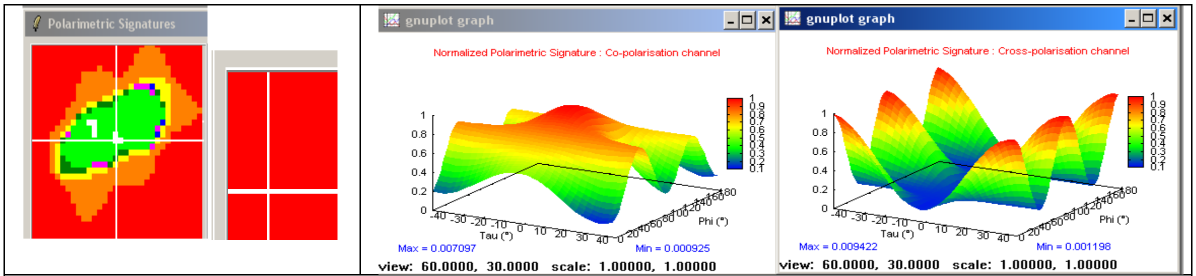


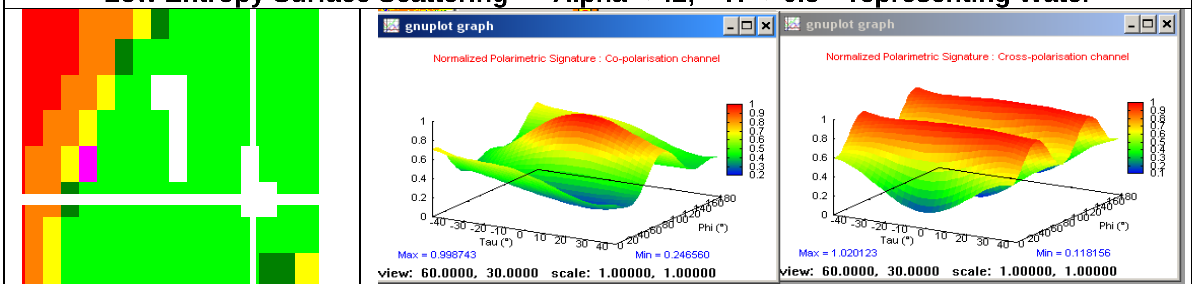
Figure 5: Histogram showing the class-wise (x-axis) distribution of percentage of pixels (y-axis) in each class for 4 sample ships

Polarisation Signatures:

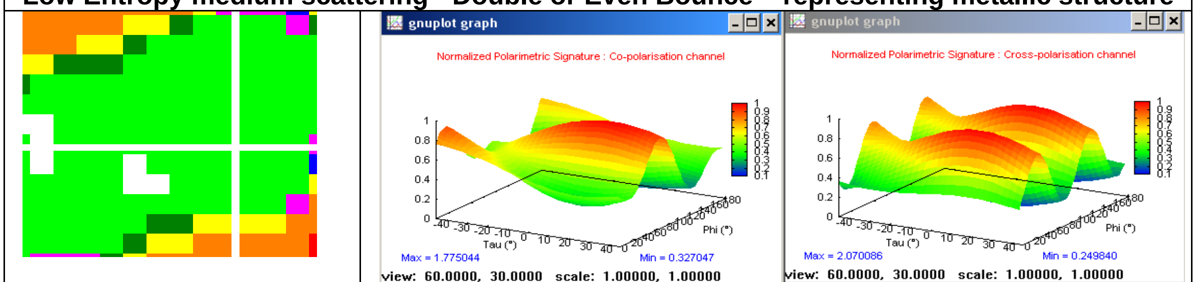
Polarisation signature is a graphical method of visualizing the target response as a function of all possible incident and backscattered polarisations. The scattering power can be determined by the four polarization variables viz., incident and backscattered orientation and ellipticity. Polarisation signatures for different classes of the ship in the above classified image are plotted as indicated in figure 7. It is observed that the signatures correspond to signatures of known elemental targets like surface, dihedral, volume etc., making it possible to infer the type of scattering process that is taking place which in turn helps in better detection and identification of scatterers in the object of interest.



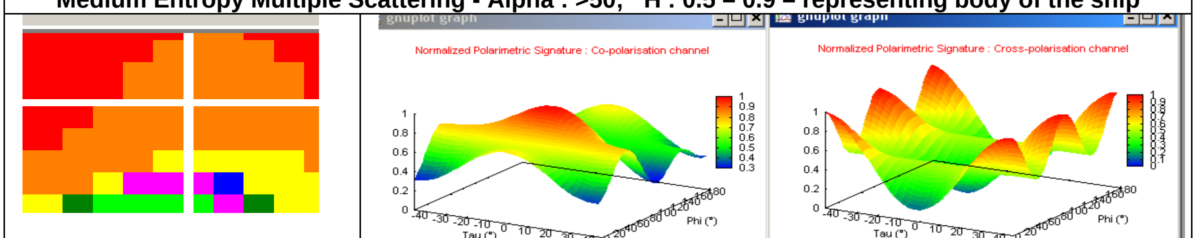
Low Entropy Surface Scattering – Alpha < 42; H < 0.5 – representing Water



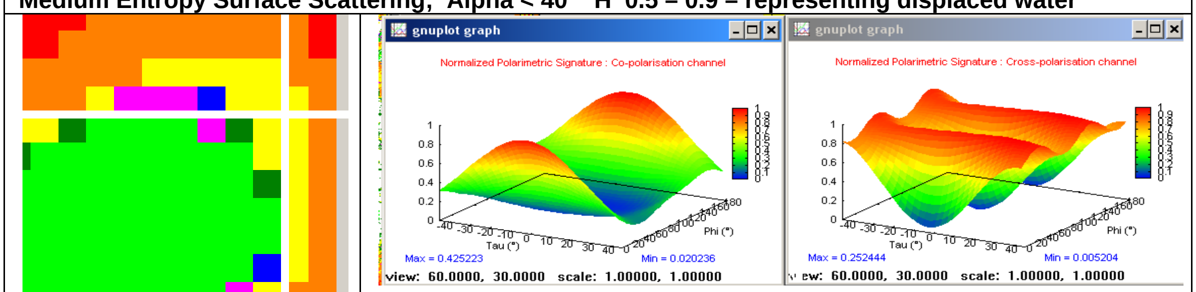
Low Entropy medium scattering - Double or Even Bounce – representing metallic structure



Medium Entropy Multiple Scattering - Alpha : >50; H : 0.5 – 0.9 – representing body of the ship



Medium Entropy Surface Scattering; Alpha < 40 H 0.5 – 0.9 – representing displaced water



Medium Entropy Dipole Scattering; 40 < Alpha < 50 H <= 0.9 – representing ship – water boundary

Figure 7: 3D plot of Polarimetric signatures for different classes within the ship

6.0 Conclusion

The analysis results demonstrate that polarimetric SAR data can be used to improve ship detection and to provide some additional classification information. This work brings out a typical scattering mechanism like dipole scattering around the ship to help identify them. This procedure can be used to automate ship detection in SAR polarimetric data. This work may be strengthened with ground truth and also can be tried on high resolution polarimetric data like RISAT-1. The future scope of this work is to understand the typical dipole scattering mechanism found in this study.

References

1. F.Berizzi, R.Paladini, "H/a polarimetric features for man-made target classification"
2. A.Kourgli, M.Quarzeddine, Y.Oukil, A.BelhadjAissa, "Landcover identification using polarimetric SAR images" in IAPRS, vol XXXVIII, Part 7A, July 5-7, 2010
3. Liang Gao and Yifang Ban, "Investigating the performance of SAR Polarimetric Features in Land cover classification"
4. Toshifumi Moriyama, SeihoUratsula, Toshiko Umehara, MokotoSatake, AkitsuguNadai, Hideo Maeno and Kazuki Nakamura, "A study on extraction of urban areas from polarimetric synthetic aperture radar image.
5. C.C.Wackerman, K.S,Friedman, W.G.Pichel, p.Clemente Colon and X.Li, "Automatic detection of ships in Radarsat-1 SAR imagery", Canadian Journal of Remote Sensing, vol 27, no. 5, pp 568-5772001
6. K.Eidhuset, "An automatic ship and ship wake detection system for spaceborne SAR images in coastal regions", IEEE Transactions on Geoscience and Remote Sensing, vol:34, no. 4, pp.1010-1019, 1996
7. Mingsheng Liao, Changcheng Wang, Yong Wang, Xiaogang Song, "Ship detection from Polarimetric SAR Images", IGARSS 2009
8. Bo Wang, Bertrand Chapron, Gregoire Mercier Rene Garello, Ming-Xia He, "Polarimetric characteristics of ships on Radarsat-2 data"
9. S.R.Cloude and E Pottier, " A review of target decomposition theorems in radar polarimetry", IEE Transaction Geoscience Remote Sensing, vol34, no.2, pp 498-518, March 1996
10. Ursula Benz, Eric Pottier, "Object based analysis of Polarimetric SAR data in Alpha-Entropy-Anisotropy decomposition using Fuzzy classification by e-cognition"
11. V.Alberga, D.Borghys, G.Satalino, D.K.Staykova, A.Borghraef, F.Lapierre, C.Perneel, "Comparison of algorithms for the classification of Polarimetric SAR data"
12. Van Zyl, J.J., 1989, "Unsupervised classification of scattering behavior using radar polarimetry data", IEEE Transactions on Geoscience and Remote Sensing, vol GE – 27, pp 36-45
13. Freeman A, Durden S L. 1998 , " A three component scattering model for polarimetric SAR data", IEEE Transactions on Geoscience and Remote Sensing, 30 (3); 532-539
14. Advanced Radar polarimetry tutorial, Canadian Centre for remote sensing, Web site: http://www.ccrs.nrcan.gc.ca/resource/tutor/polarim/index_e.php
15. ESA Polarimetry Tutorial, ESA, 2005, web site: http://earth.esa.int/polsarpro/tutorial.html