Acta Oceanol. Sin., 2016, Vol. 35, No. 3, P. 84–89
10.10.1007/s13131-015-0817-x
http://www.hyxb.org.cn
E-mail: hyxbe@263.net

Research on polarization of oil spill and detection

CAI Yang[1], ZOU Yarong[2, 3]*, LIANG Chao[2, 3], ZOU Bin[2, 3]
[1] South China Sea Forecast Center, State Oceanic Administration, Guangzhou 510310, China
[2] National Satellite Ocean Application Services, Beijing 100081, China
[3] Key Laboratory of Space Ocean Remote Sensing and Application, State Oceamic Administration, Beijing 100081, China

Received 21 October 2014; accepted 3 March 2015

Abstract
The SAR (Synthetic Aperture Radar) has the capabilities for all-weather day and night use. In the case of determining the effects of oil spill dumping, the oil spills areas are shown as dark spots in the SAR images. Therefore, using SAR data to detect oil spills is becoming progressively popular in operational monitoring, which is useful for oceanic environmental protection and hazard reduction. Research has been conducted on the polarization decomposition and scattering characteristics of oil spills from a scattering matrix using all-polarization of the SAR data, calculation of the polarization parameters, and utilization of the CPD (Co-polarized Phase Difference) of the oil and the sea, in order to extract the oil spill information. This method proves to be effective by combining polarization parameters with the characteristics of oil spill. The results show that when using Bragg, the oil spill backscattering machine with Enopy and a mean scatter α parameter. The oil spill can be successfully identified. However, the parameter mechanism of the oil spill remains unclear. The use of CPD can easily extract oil spill information from the ocean, and the polarization research provides a base for oil spill remote sensing detection.

Key words: oil spill, polarization, detection, SAR

Citation: Cai Yang, Zou Yarong, Liang Chao, Zou Bin. 2016. Research on polarization of oil spill and detection. Acta Oceanologica Sinica, 35(3): 84–89, doi: 10.10.1007/s13131-015-0817-x

1 Introduction

With the rapid development of China's economy, the oil consumption demand has sharply increased, which leads to greater amounts of oil transport by ocean and increases the likelihood of oil spills. Oil spills often result in large-scale ocean pollution, which not only harms the oceans, natural environment and ecological resources, but also leads to mass mortality of marine life, economic loss, and serious harm to human health. The oil spill damage has also gained the attention of governments. Since 2006, there have been increasing numbers of oil spill accidents in the oceans within Chinese jurisdiction, In particular, the Dalian Xingang oil spill of July 2010, which was caused by pipeline rupture, caused a great deal of harm on a large scale, and has led to widespread attention across China.

In recent years, studies have conducted research regarding oil spillage detection using polarimetric SAR data. These studies can be divided into two categories: first, detecting oil spills based on polarization decomposition, and secondly, detecting oil spills using Co-polarized Phase Difference (CPD).

Migliaccio et al. (2007, 2009) used SIR-C/X-SAR data, through polarization coherent scattering matrix eigenvalue and eigenvector,in order to calculate the entropy (Entropy H) and the mean scattering angle (α), and constructed an H/α classification plane for image classification.

Nunziata et al. (2007), Migliaccio et al. (2009) used SIR-C/X-SAR data to validate the capabilities with polarization phase CPD (Co-polarized Phase Difference) for oil spill detection (Nunziata et al., 2007; Migliaccio et al., 2009).

Through the multi-look C, L-band phase and the standard deviation of oil spill research, Migliaccio et al. (2009), Velotto et al. (2010, 2012) proposed two bands which could be used to identify oil spills, Furthermore, using a C-band to detect oil spills is considered to be effective than using the L-band. They developed an oil spill detection method that computes with phase based on the weak damping performances using the dual-polarization SIR-C/X-SAR and TerraSAR-X SAR data (Migliaccio et al., 2009; Velotto et al., 2010; Velotto et al., 2012). Migliaccio et al. (2011) calculated the phase differences as well as the phase difference between the standard seawater and the oil spill, in order to extract the oil spill information for the Gulf of Mexico oil spill in 2010 (Migliaccio et al., 2011). Velotto et al. (2011) calculated the phase of the two-channel correlation with standard deviation using the relationship between the dual-polarized channel polarization model, and obtained a good results (Velotto et al., 2011). Based on the relationship between S_{VV} and the S_{HH} error covariance, Salberg et al. (2012) proposed a Bragg scattering generalized likelihood ratio based on a linear model in order to distinguish the actual oil spill and from its look-likes (Salberg et al., 2012).

The application polarization decomposition method to extract oil spillage information is another area of research study.

When comparing the entropy, scattering angle, and anti-en-

Foundation item: The National Natural Science Foundation of China under contract No. 41376183; the High Resolution Images Services Special Projection for ocean applications; the Oceanography Public Welfare Scientific Research Project-Marine of China under contract No. 201205012.
*Corresponding author, E-mail: zyr@mail.nsoas.org.cn

tropy parameters Migliaccio et al. (2007) believed that using an entropy parameter to detect oil spillage was more effective than using an anti-scattering angle parameter (Migliaccio et al., 2007). Wang et al. (2010) carried out oil spill information extraction by utilizing several anti-entropy, polarization correlation coefficients, polarization SPAN and their combinations (Wang et al., 2010). Studying the relationship between S_{HH} and S_{VV}, Zhang et al. (2011) found that using the consistency coefficient is more effective than using entropy and the scattering angle parameter for oil spill identification (Zhang et al., 2011). From the C3 polarization covariance matrix, Skrunes et al. (2012) developed a method to distinguish crude oil and vegetable oil through a variety of polarization entropy, scattering angle, standard deviation of phase, and polarization ratio decomposition parameters using Radarsat-2 data (Skrunes et al., 2012).

Salberg et al. (2012) studied entropy, scattering angle, and anti-entropy oil spill scattering parameters using L-band SAR data, and considered the coherent matrix eigenvalues as the most reliable indicators in the U.S. Gulf of Mexico oil spill accident, U.S.A (Skrunes S et al., 2012).

Most scholars have done resrarch on detection of oil spill by means of CPD parameter, but combination of this parameter with other parameters to detect oil spill is seldom done.

Applying the polarization decomposed method can efficiently extract oil spill information from sea water, and the polarization phase method can effectively distinguish biofilm form oil spill. Due to the oil spill's weak scattering, it is difficult to distinguish the oil from look-alikes, which requires further study of the scattering of the chacateristics of an oil spill, combined with more sophisticated testing in oil spill information extraction. This study focuses on the polarization decomposition for oil spills detection.

2 Data and methods

2.1 *Study area*

The study area is in the northwest area of Changdao Island. Figure 1 shows the study area location.

2.2 *Data*

The data used in this study are full fine polarization Radarsat-2 with a range resolution of 5.2 m, an azimuth resolution of 7.6 m, and a width of 25 km×25 km. The original data were acquired on August 19, 2011. The data of the near range incidence angle is 36.4°and the far range incidence angle of is 38°. The geometric correction was conducted by the data provider.

2.3 *Methods*

In 1986, Cloude put forward a characteristics vector analysis method based on coherent matrix, which contained all of the scattering mechanisms. According to the decomposition method, we can determine the three characteristic parameters with clear physical meaning parameters as fellows: the scattering angle α, entropy H, and polarization of the anti-entropy entropy A.

(1) Scattering angle α

There is a physical mechanism interrelated between the scattering angle α values and the scattering processes, which corresponds to the scattering from odd (surface scattering) (α=0°) to dipole scattering (scattering) (α=45°), and to the even scattering (dihedral angle scattering) (α=90°) in the changes.

(2) Entropy H

Scattering entropy ($0 \leqslant H \leqslant 1$) represents a randomness of the scattering medium from isotropic by the scattering (H=0) to completely random scattering (H=1).

If the H value is very low (H<3), the system shows weak depolarization, and the advantage scattering mechanisms are an eigenvector corresponding to the largest eigenvalue; if the H value is high, the targets show a strong depolarization; if H is 1, we find zero polarization information. Scattering is actually a random noise process, and the formula is as fellows:

$$H = -\sum_{i=1}^{3} P_i \log_3 P_i, \tag{1}$$

Fig. 1. Study area.

$$P_i = \lambda_1 / (\lambda_1 + \lambda_2 + \lambda_3), \quad (2)$$

where P_i, also called the probability of the eigenvalue λ_i, represent the relative importance of this eigenvalue respectfully to the total scattered power. And λ_1, λ_2, λ_3 are a coherent eigenvector matrix.

(3) Anisotropy *A*

Entropy polarization scattering provides information in the same resolution element of the overall scattering mechanism, However, under a medium or low entropy, Entropy (λ_1>λ_2, λ_3) situation, the entropy cannot provide the scattering relation between the two smaller eigenvalues λ_2 and λ_3. At this time the anisotropy polarization A should be considered, as shown in the expression formula below:

$$A = \frac{\lambda_2 - \lambda_3}{\lambda_2 + \lambda_3}. \quad (3)$$

Anisotropy is a supplement parameter for entropy, due to it showing the size relationship between two weak scatterings and the expected scattering component of the dominant scattering mechanism. Only when *H*>7, is the anisotropy considered as a useful parameter to identify targets, or that the anisotropy contains high random noise(Wang et al., 2008). When the *H* value becomes larger, the quantity of useful polarization to be identified decrease. When the *H* value increases, the anisotropy has obvious meaning, and can be to carry out the classification.

(4) Co-polarized Phase Difference (CPD)

The polarimetric SAR system scattering matrix takes *S* as the base recording unit, which represents the polarimetric relationship between the transmitted and received electric field as fellows:

$$E_s = \frac{e^{-jkr}}{r} S\, E_i = \frac{e^{-jkr}}{r} \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} E_i, \quad (4)$$

$$S = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}. \quad (5)$$

The scattering coefficient can be written in the complex amplitude and phase:

$$S_{pq} = |S_{pq}|\, e^{j\phi_{pq}}, \quad (6)$$

where, $|S_{pq}|$ is the scattering amplitude, ϕ is the phase, and *p*, *q*=*H*, *V* are the transmit and receive electromagnetic polarization respectively. Therefore:

$$S = \begin{bmatrix} |S_{HH}|\, e^{j\phi_{HH}} & |S_{HV}|\, e^{j\phi_{HV}} \\ |S_{VH}|\, e^{j\phi_{VH}} & |S_{VV}|\, e^{j\phi_{VV}} \end{bmatrix}. \quad (7)$$

Taking the first element of the scattering matrix phase as the reference phase S_{HH}, the formula can be expressed as a relative phase:

$$S = e^{j\phi_{HH}} \begin{bmatrix} |S_{HH}| & |S_{HV}|\, e^{j\phi_x} \\ |S_{VH}|\, e^{j\phi_x} & |S_{VV}|\, e^{j\phi_c} \end{bmatrix}, \quad (8)$$

where, ϕ_c is the co-polarization phase angle:

$$\phi_c = \phi_{VV} - \phi_{HH}. \quad (9)$$

CPD is defined as the standard deviation:

$$\mathrm{CPDstd} = \mathrm{std}\rho \left(\frac{1}{L} \sum_{i=1}^{L} (S_{HH} S_{VV}^*) \right), \quad (10)$$

where, std is the standard deviation, *L* is based on the number, and ρ is the phase difference calculation.

The CPD standard deviation and channel correlation coefficients can be evaluated based on the channels correlation. In the area of low correlation, the phase is strongly sensitive to the correlation coefficient; it is very useful to distinguish oil spills and look-alikes.

3 Results and analysis

3.1 *Polarization decomposition parameter calculation*

We obtained the polarization parameters of polarization scattering parameters entropy, scattering angle, and the anti-entropy diagram through utilizing PolSARpro software, and the calculation results are shown in Fig. 2. In the parameters of the entropy data, the scattering angle can be clearly extracted for the spill information against the sea water background in the Bragg scattering. Due to the multiple scattering of the oil-platform and ship, light dots are evident in the image; using an anisotropy parameter in the image can clearly show the information pertaining to the oil-platform and ships,oil-platform and ships information. Many light spots around the oil-platform in the image caused interference information extracted from the nearby oil-platform, therefore, it was difficult to identify oil spill information in this location. While using anisotropy as a supplement for entropy, when *H*>0.7, the anti-entropy parameter can be used to identify the oil spill. When the value of the entropy is lower, the second and third characteristic values are greatly affected by noise, therefore, the anti-entropy also contains a lot of noise, because the entropy parameter values in Fig. 2 is below 0.7. Anisotropy parameters image having amounts of noise not possible to identify the oil

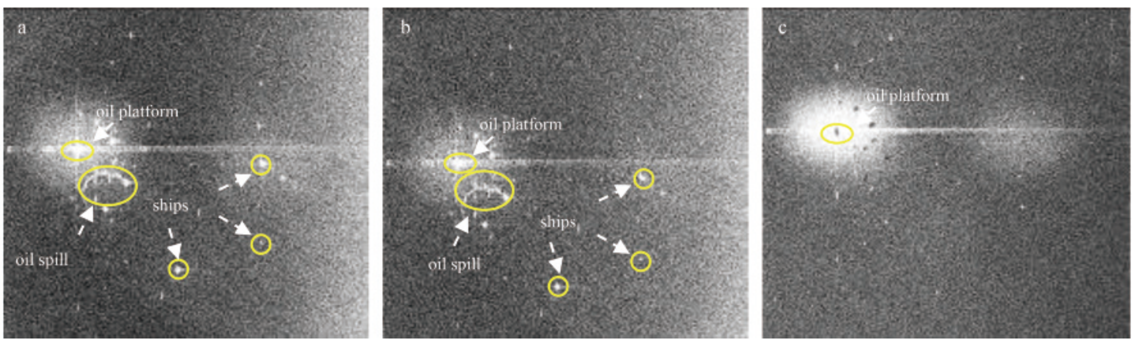

Fig. 2. Entropy, scattering angle, anisotropy images. a. Entropy, b. scattering angle and c. anisotropy.

spill information.

We put all samples of seawater, oil and water mix selected from entropy, scattering angle, anisotropy image in ENVI software, the results as shown in Fig. 3. Using entropy parameter can significantly distinguished oil spill from seawater. Compared with seawater, oil spill lies in a high value area. It is more difficult to distinguish oil spill from mix seawater. What scattering angle parameter performance is same as entropy parameter does, while using anisotropy to distinguish oil spill from mix seawater is not obvious.

The scattering entropy ($0 \leqslant H \leqslant 1$) indicates an isotropic scattering from the scattering (H=0) to the fully random scattering (H=1). When an oil spill occurs, sea water mixes with the oil spills, and a chemical emulsification process is produce, the oil spill scattering matrix is not the only results. The oil and seawater possess scattering characteristics, shown as random noise processes occur, thus the, entropy and scattering angle show non-uniformity. The seawater scattering is Bragg scattering, and α shows the surface scattering mechanism, seawater appears dark in the image, while the oil and seawater mixture show dipole scattering characteristics, which are bright areas in the image. The anisotropy is supplemented for entropy, but the entropy is low, and the oil spill information cannot be effectively extracted from seawater background.

The oil spill information can be efficiently extracted from the seawater through an H alpha plane,as shown in Fig. 4a, the oil and seawater show surface scattering characteristics. However,the oil spill is indicated as weaker in comparison with seawater. Therefore, the oil spill information can be extracted. The oil platforms and vessels are shown as bright spots in the image due to their dipole scattering properties. Compared analysis H_{alpha} and $H_{\text{alpha plane}}$, platforms and ships scattered in as shown in Fig. 4b 3–4 region, and belong to the entropy dihedral angle scattering of particles with the anisotropic regions, where seawater is 5, and 8 is the spill area for Bragg and random surface scattering.

3.2 *Parameter combinations*

Given the polarization decomposition characteristics for the decomposition of the polarization parameters, the scattering matrix was derived, we constructed the entropy, alpha angle and antientropy, and their combine parameters (1–H), (1–A) as follows: in order to constitute a combination of polarization characteristic spectrum. This polarization characteristic spectrum has

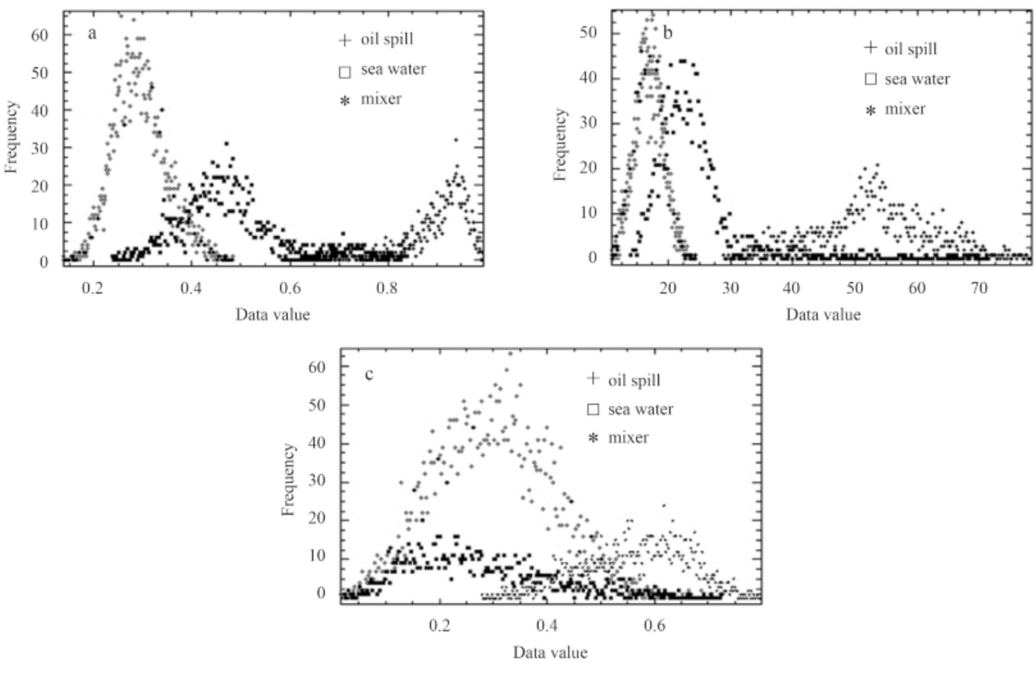

Fig. 3. Entropy, scattering angle, anisotropy and their sample histogram comparison.

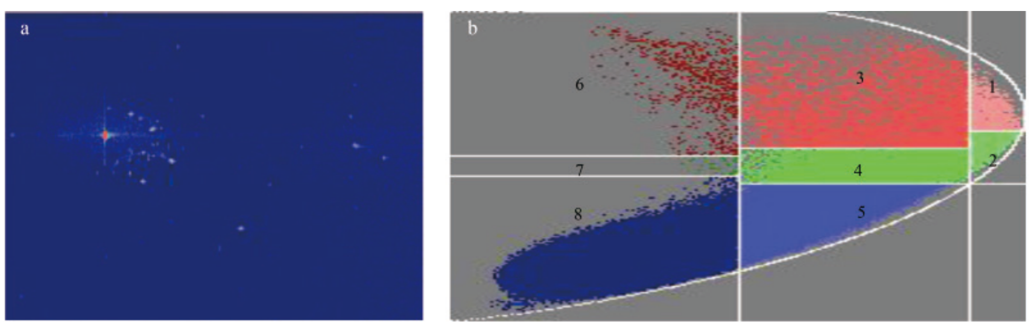

Fig. 4. $H_{\text{alpha classification}}$ (a) and $H_{\text{alpha plane}}$ (b).

four parts, one kind of scattering parameters (1–*H*) (1–*A*); one type of scattering mechanism is dominant, the other two have scattering of a relatively smaller parameter *H*(1–*A*), relative to scattering of HA, and a single of even, relatively uniform random scattering of a (1–*H*).

When analysis the combination of the parameters, and comparing it with the vessel and the sea scattering, the oil spill scattering was found to be weak on the whole. When the oil spill scattering parameter values are concentrated in the low areas, and the scattering parameter combinations are showing normal, the impact of oil spill information by vessels(Fig.5d) exists in the image. For the *HA* showing two scatterings, the oil spill information was difficult to distinguish(Figs 5b and c), as it showed a mixture in the image, indicating that the oil spill scattering was strongly impact by vessels. The (1–*H*) (1–*A*) was scattered with the surface scattering characteristics, and the vessel and oil spill information was not easy to distinguish, However, in the low areas, the oil spill information could be efficiently extracted. *A*(1–*H*) exhibited a consistently a trend of single, dual, and random scattering, and the oil spill information could efficiently be extracted from in the low zone information(Fig.5a).

3.3 *Co-polarized Phase Difference*

We obtained co-polarized phase through matrix calculation T3 using Radarsat-2 data, then calculated the standardized CPD , as shown in Fig. 6a, the information of oil spill and vessels are obviously in this image. However, sidelobe is not the response of the oil platform. Furthermore, Fig. 6b shows the noise reduction. There were no difference for information between oil spill and oilplatform in line with entropy and scattering angle. But the results calculated from the vessel CPD information and the oil spill, can obviously identify the oil spill from oilplatform shown in Fig. 6a. By using a phase difference calculation, false alarms can be removed, which improve the oil spill information extraction accuracy.

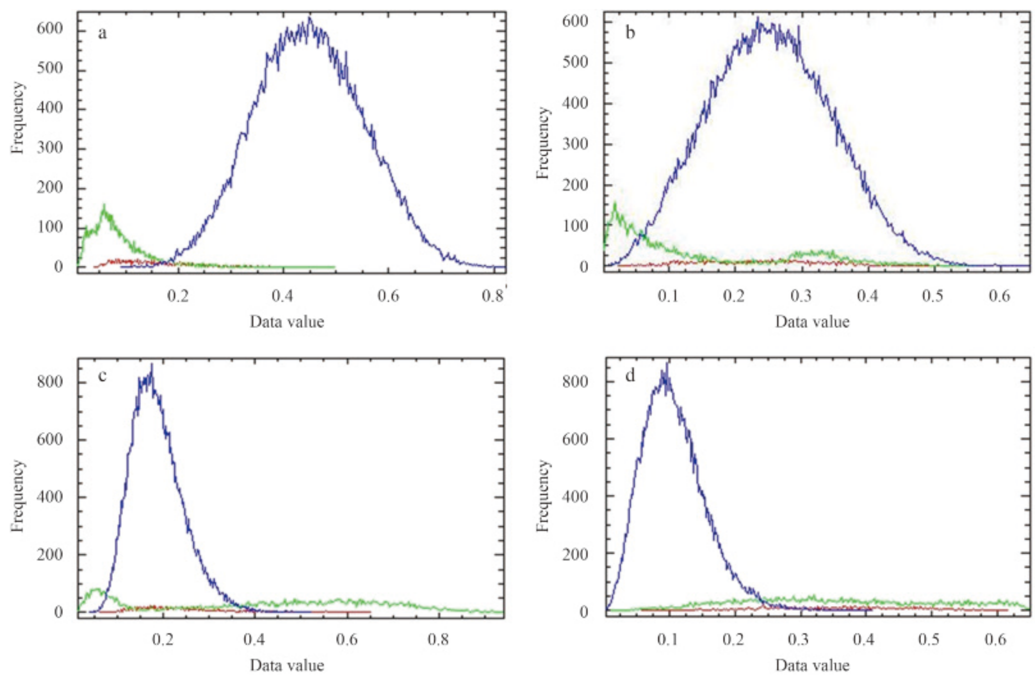

Fig. 5. Parameter combinations.

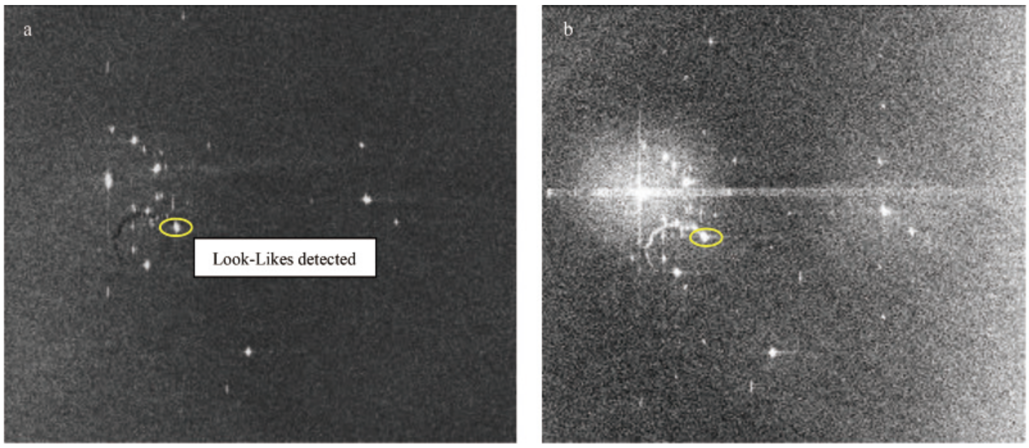

Fig. 6. Using CPD and entropy to extract information and compare a. CPD and b. entropy.

4 Conclusions and discussion

Using remote sensing to detect oil spills is one of the marine environment's remote sensing technologies. The full polarization SAR includes the oil spill scattering information. Due to all polarize SAR having more information and the ability polarization the scattering characteristics of an oil spill, taking all polarization SAR data into account in order to detect oil spill is more efficient than only using single SAR data. Oil spill scattering characteristics are surface scattering. The polarization entropy (H), and the scattering angle (α) can have better response to the oil spill, while the anti-entropy (A) and other parameters of the performance spectrum of the oil spill are not as obvious. When calculating the phase difference (CPD) extracted from the oil spill information in the sea water, polarization studies assist in providing a scientific basis for remote sensing to detect oil spills.

Oil spill detection by means of CPD and other parameter is subject to the change of marine environment. Therefore the study of marine environment is conductive to accuracy of oil spill detection.

Acknowledgements

The authors would like to thank Zhang Shengli of Beijing International Studies University for paper proof. We thank the two anonymous reviewers for their suggestions to improve the manuscript.

References

Migliaccio M, Gambardella A, Tranfaglia M. 2007. SAR polarimetry to observe oil spills. IEEE Transactions on Geoscience and Remote Sensing, 45(2): 506–511

Migliaccio M, Nunziata F, Gambardella A. 2009. On the co-polarized phase difference for oil spill observation. International Journal of Remote Sensing, 30(6): 1587–1602

Migliaccio M, Nunziata F, Montuori A, et al. 2011. A multifrequency polarimetric SAR processing chain to observe oil fields in the Gulf of Mexico. IEEE Transactions on Geoscience and Remote Sensing, 49(12): 4729–4737

Nunziata F, Gambardella A, Migliaccio M. 2007. Dual-polarized SAR data for oil spill detection. In: ESA eds. Proc 'Envisat Symposium 2007'. Montreux, Switzerland: ESA SP-636, 23–27

Salberg A B, Rudjord O, Solberg A H S. 2012. Model based oil spill detection using polarimetric SAR. In: Proc IGARSS, 5884–5887

Skrunes S, Brekke C, Eltoft T, et al. 2012. An experimental study on oil spill characterization by multi-polarization SAR. In: EUSAR, eds. 9th European Conference on Topic (s): Fields, Waves & Electromagnetics. EUSAR, 139–142

Velotto D, Lehner S, Soloviev A, et al. 2012. Analysis of oceanic features from dual-polarization high resolution x-band SAR imagery for oil spill detection purposes. In: 2012 IEEE International Geoscience and Remote Sensing Symposium (IGARSS). Munich: IEEE, 2841–2844

Velotto D, Migliaccio M, Nunziata F, et al. 2010. Oil-slick observation using single look complex TerraSAR-X dual-polarized data. In: IGARSS, eds. 2010 IEEE International Geoscience and Remote Sensing SymposiumI. Honolulu: IEEE, 3684–3687

Velotto D, Migliaccio M, Nunziata F, et al. 2011. Dual-polarized TerraSAR-X data for oil-spill observation. IEEE Transactions on Geoscience and Remote Sensing, 49(12): 4751–4762

Wang Chao, Zhang Hong, Chen Xi, et al. 2008. Full polarization synthetic a perture radar image pro cessing Beijing: Science Press

Wang Wenguang, Lu Fei, Wu Peng, et al. 2010. Oil spill detection from polarimetric SAR image. In: Int Conf Signal Process, 832–835

Zhang Biao, Perrie W, Li Xiaofeng, et al. 2011. Mapping sea surface oil slicks using Radarsat-2 quad-polarization SAR image. Geophys Res Lett, 38(10), doi: 10.1029/2011GL047013