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DECOMPOSITION METHODS FOR DETECTION OF OIL SPILLS BASED ON RISAT-1 SAR IMAGES

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Abstract

The objective of this paper is to present the methods of oil spill detection and segregation of look a-likes using SAR images of India's first Radar Imaging Satellite (RISAT-1) that are based on Hybrid Polarity SAR architecture. The Hybrid polarity SAR will transmit pulses in circular polarization and receive echoes in linear polarizations. Detection of oil spills on sea surface is a complex process, because some of the natural phenomena, which resemble oil spills (look a-likes) frequently occur, particularly at low wind conditions. Rain cells, wind front areas, organic film, grease ice are some examples of look a-likes. The images of the Oil, spilled for experimental reasons on ocean surface near Norway were acquired by RISAT-1 and the Single Look Complex images are obtained. Stokes parameters S1,S2,S3,S4 are derived for the images. From these Stokes parameters, the relative phase, orientation, ellipticity, and polarization angle are calculated. Further, four decomposition methods viz;, m-chi (ellipticity parameter), m-delta (relative phase parameter), and the new m-psi (orientation parameter), m-alpha (polarization angle), are applied to detect the oil slick and also to isolate look a-likes. The relative phase, orientation angle, ellipticity, and polarization angle parameters will change their characteristics with respect to dielectric constant of the sea surface material. Since the dielectric constant of the oil spill is different from that of a the sea and look a-likes, the possibility to separate the oil spill area from the sea and look a-likes is explored using all the four decomposition methods. The preliminary results are encouraging and the viability of unsupervised classification based on decomposition methods for identification of oil spill regions by Hybrid Polarity SAR images is presented in this paper.

Keywords-SAR, RISAT-1, Oil Spill, Decomposition methods

Introduction

The Petroleum oil production has increased in recent years, and as a result, the shipment of oil from producing countries to procuring countries has increased. Repeated oil spills affect marine eco system, human health and therefore, the Oil spill pollution should be monitored to take mitigation measures. Oil spill can be monitored using Ships, Aeroplanes and Satellites. Ships can monitor upto 3 Km. Monitoring using airborne sensors is very expensive and only limited area can be scanned. Satellite based monitoring using optical sensor or Synthetic Aperture Radar(SAR) is most advanced and efficient way of monitoring the entire ocean surface. The SAR has an advantage of all weather condition and is independent of cloud coverage and intensity of sun light. Until recent years, amplitude images of SAR were used for observation of oil spill pollution. With availability of complex and smart SAR sensors on board spacecrafts, utilization of polarization and phase components has commenced in recent years making the oil spill detection relatively simple and reliable.

In global scenario, the pollution control board in Norway uses the oil spill detection scheme that is based on statistical method of Bayesian classification, developed by Anne H. Schisted Solberg [1]. In Italy the oil spill detection using Neural Network was developed by Fabio Del Frate [2]. In Greece, the Oil spill detection using neural network method is developed by K. Topouzelis, et. al [4]. Oil spill detection in SAR images by fractal dimension estimation is explained by Giuliano Benelli, G., Garzelli [5]. In another method oil spill characterisation by SAR image and synergistic data was developed by Fanny Girard Ardhuin [7]. Nirupam Sarkar and B.B. Chaudhuri of India proposed the Fractal Dimension method, for oil spill detection using SAR images[8].

RISAT-1 is the first Indian Radar Imaging Satellite. On 26-Apr-2012 RISAT-1 satellite was launched byPSLV-C19 launch vehicle. RISAT-1 is the first Earth satellite, with Hybrid polarity SAR. In this paper, we attempted to propose an unsupervised method based on application of decomposition methods for oil spill detection with RISAT-1 Hybrid polarity SAR images.

The subsequent sections of this paper, describes the hybrid polarity SAR architecture of RISAT-1, RISAT-1 operating modes and imaging parameters [14], Poincare polarization sphere, EM field characterization, and Stokes Parameters, decomposition methods. The last sections of the paper describes about results and conclusion.

Hybrid Polarity SAR Architecture

From past four to five decades, linear polarization has been widely used in airborne and satellite imaging radars [9][10][11]. In linear polarization method, the transmission and reception is in linear polarization, and in order to get the fully polarimetric data, two transmitters are required. In hybrid polarimetric SAR, the single transmitter is usable to get the polarimetric data and the reception is in linear polarization. From the received vertical and horizontal polarization, relative phase can be obtained, which is essential for deriving the Stokes parameters. From the Stokes parameters various child products can be generated, which is use full for the required classification[16].

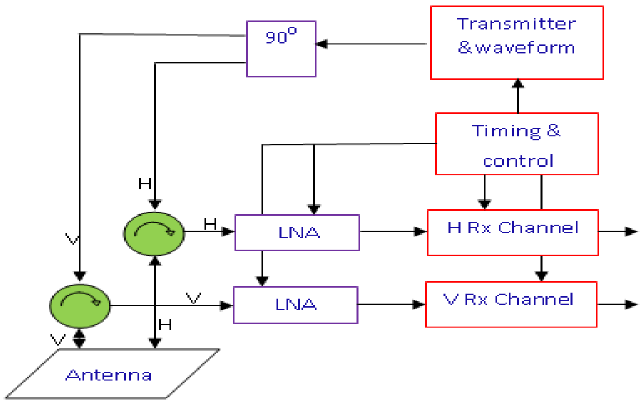

Fig 1: Hybrid polarity SAR architecture of RISAT-1

Hybrid polarity SAR architecture with circular transmission and linear reception has advantage compared to conventional linear transmission and reception. The hybrid polarity SAR receives equal signals in linear reception due to circular transmission, so that calibration and measurement of amplitude and phase information is easy[10]. Since hybrid polarity SAR transmission is in circular polarization, it gives more information about the target. The circular polarization cycles through all possible polarization states. By using this rich backscatter information it is possible to derive the Stokes parameters. Stokes parameters are necessary for analysis and classification of the target.

A typical generic diagram of hybrid-polarity SAR architecture is shown in figure1[11]. The architecture mainly consists of transmitter, receiver and antenna. The transmitter consists of transmitter, 90^0 phase shifter, microwave switch and antenna. The transmitter output is fed to phase shifter in order to produce the horizontal and vertical polarization components. The V&H polarization components are fed to antenna through switch. The antenna will radiate the circular polarized component if the H and V feeds are driven simultaneously and 90^0 out of phase. The receiving section consists of antenna, microwave switch, LNA and receivers. The V&H polarized signal is received simultaneously and fed to corresponding LNA's and receivers. The output of the receiver is fed to relative phase measurement meter. The Timing and control section of the hybrid polarity SAR controls the output of the transmitter. It enables & disables the transmitter & low noise amplifiers at specified intervals. Once the output of transmitter is enabled for specified duration, the remaining time will be reserved for the reception of the reflected waves and the switch position will be configured for reception.

RISAT-1 Operating Modes and Imaging Parameters

RISAT-1[14], is the first Radar Imaging Satellite of India and also the first earth observation satellite with Hybrid polarity SAR architecture. RISAT-1 with SAR payload is placed in polar Sun synchronous orbit with 6am-6pm equator crossing. The altitude of the satellite is maintained at 536 Km. The RISAT-1 carries the multi-resolution, multi-swath, multi-polarisation SAR system as the sole payload. RISAT-1 SAR is capable of taking conventional mode of imaging as well as polarimertic mode of imaging, such as Mono polarization, Dual polarization, Hybrid polarimetry and Quadrature polarization. In Mono polarization mode, the single polarization is transmitted and same polarization is received. In case of Dual polarization, the transmitter will send either vertical or horizontal polarization and the reception will be in both the polarizations. In case of Hybrid Polarimetry, right or left circular polarization is used for transmission and reception is done in two linear orthogonal polarization. In this mode of operation two magnitude images and phase information can be obtained. In quad polarization mode, the transmission is done using two linear polarizations and reception is done in two polarizations for each channel. The SAR payload is operated in C-band with frequency 5.35 GHz.

RISAT-1 SAR has following imaging modes: Fine Resolution Stripmap Mode-1 (FRS-1): 3 m (azimuth) X 2 m (range) resolution, 25 km swath, Minimum signal nought of -17dB; Fine Resolution Stripmap Mode-2 (FRS-2 Quad pol.): 9 m (azimuth) X 4 m (range) resolution, 25 km swath, Minimum signal nought of -20dB; Medium Resolution ScanSAR Mode (MRS): 21-23 m (azimuth) X 8 m (range) resolution, 115 km swath, Minimum signal nought of -17dB; Coarse Resolution ScanSAR Mode (CRS): 41-55 m (azimuth) X 8 m (range) resolution, 223 km swath, Minimum signal nought of -17dB; High Resolution Spotlight Mode (HRS): 1 m (azimuth) X 0.7 m (range) resolution, 10 X 10 km (10 X 100 km experimental) spot, Minimum signal nought of -16dB. The SAR can image either side of the track by roll tilting. However, in one orbit, only one side of the orbit can be imaged. On either side, imaging area is restricted over 659 km distance starting at stand-off distance of 107 km. The FRS-1 and MRS modes operate in Strip map mode and can be configured to operate in hybrid polarity SAR, with circular transmission and linear reception. The hybrid polarity SAR technique is used in Mini-RF aboard NASA's Lunar Reconnaissance Orbitor, together with its precursor, Mini-SAR on India's lunar Chandrayaan-1 satellite[15][19][28] in order to find water and ice in the moon.

Poincare Polarization Sphere and Stokes vector

The Poincare sphere shown in figure 2 for representation of wave polarization using the Stokes vector. Using Poincare sphere any polarization state can be represented in terms of sphere. In this sphere, the equatorial plane represents the linear polarization state, the x-axis represents the horizontal polarization and y-axis represents the vertical polarization. The north pole and south pole represents the left hand and right hand circular polarization state respectively.

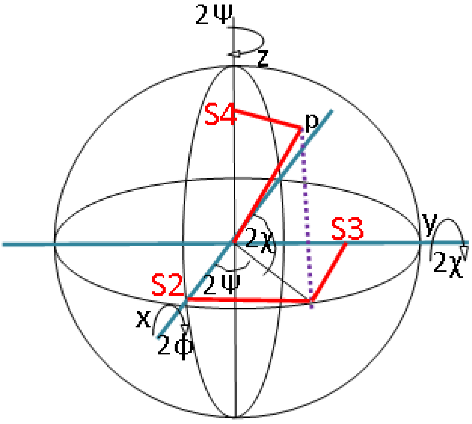

Fig 2 Poincare sphere representation

The British scientist Gabriel Stokes introduced the 4 element vector $[S1,S2,S3,S4]^T$, it is known as Stokes vector [15,16]. The Stokes parameter, (S1,S2,S3,S4) can be used as a part of the Poincare sphere. S1 represents the degree of polarization and is used to represent the radius of Poincare sphere. Normally Stokes parameter S2 represents the linear polarization component in the electromagnetic wave. So in Poincare sphere, the x-axis represents the linear polarization component, the parameter S2 is used to represent the x-axis of the sphere. In a similar way S3 represents the polarization component at 45^0 with respect to x-axis. The S4 parameter represents the left hand circular polarization component. The S4 can be used to represent the z-axis of the Poincare sphere. The ellipticity and orientation of the electromagnetic wave is represented by χ and ψ. The 2ψ and 2χ represents the longitude and latitude of the wave. From the figure 2 we can see that the relation between ellipticity and orientation of electromagnetic wave and latitude and longitude of the Poincare sphere, respectively.

EM Field Characterization, and Stokes Parameters

The four parameters are sufficient to characterise the partially polarized electromagnetic wave. The four parameters are, the amplitudes of two orthogonal polarized wave, the relative phase between them and the polarized portion of the electromagnetic wave. In classical optics, these parameters are expressed in terms of 2 X 2 coherency matrix 'M', but measurement of relative phase is one of the challenging tasks. In electromagnetic wave theory these measurements are possible. These parameters are formulated by G.G.Stokes in terms of four real numbers and it is known as Stokes parameters.

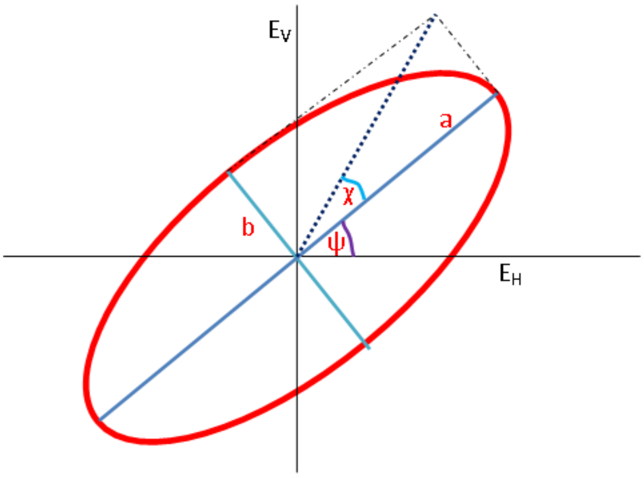

Fig 3 Polarization ellipse showing the ellipticity χ and orientation angle ψ [21] .

Dr Raney suggested that to get optimal result in SAR, transmission needs to be done in circular and reception in horizontal and vertical polarization. The phase angle between horizontal and vertical polarization should be preserved. This configuration preserves complete information about object without any loss of information. This method is used for identification of water-ice on the moon's surface in India's chandrayaan-1 mission as well as in Mini-RF aboard NASA's Lunar Reconnaissance Orbitor[15]. Received linear polarization can be represented by Stoke's parameters[16] and these Stoke parameters are converted to red, green and blue components using trigonometric function.

The vertical and horizontal polarized components are the basis vectors for any electromagnetic wave. That is any electromagnetic wave can be described as vector sum of two orthogonal polarized component, such as vertical and horizontal polarization components. Figure 3 shows the fully polarized wave ellipse in general pattern. The orientation angle ψ represents the angle between X-axis and semi major axis, and can take the values between 0^0 and 180^0. If ellipticity angle is 0^0, then it represents the linear polarization, if angle is 45^0, then it represents the circular polarization. The ellipticity is defined as χ= arctan(b/a), which can take values between -45^0 to $+45^0$.

The Stokes parameter can be used for describing the polarization state of the electromagnetic wave, using horizontal and vertical polarized component. The Stokes vectors is given below.

$$S1=avg(|E_H|^2+|E_V|^2) \quad (1)$$

$$S2=avg(|E_H|^2- |E_V|^2) \quad (2)$$

$$S3= 2\,Re\,(avg(E_H E_V^*)) = 2E_H\,E_V \cos\,\theta \quad (3)$$

$S4 = -2\ \mathrm{Im}(\mathrm{avg}(E_H E_V^*)) = -2\, E_H\ E_V \sin\theta$ (4)

where |.| is the absolute value, * is the complex conjugate, avg( ) is average and θ is the relative phase between the two components.

The Stokes parameter S1 is always equal to the total power of the wave. S2 is equal to power in the linear vertical or horizontal polarized components . S3 is equal to the power in the linearly polarized components at tilt angles Ψ = 45 deg or 135 deg. S4 is equal to the power in the right handed and left handed circular polarized components. If any of the parameters S2,S3 or S4 has a non zero value, it indicates the presence of a polarized component in the plane wave.

Degree of polarization : when the electromagnetic wave is partially polarized, it can be expressed as the sum of a completely polarized and a completely un polarized wave. The degree of polarization is the ratio of the polarized power to the total power, and in terms of the Stokes parameters, the degree of polarization is given by[18]

$dp = (S2^2 + S3^2 + S4^2)^{1/2}/S1$ (5)

Circular polarization ratio gives the
$CPR = (S1-S4)/(S1+S4)$ (6)
CPR=Same sense polarization/Opposite sense polarization.

The circular polarization is evaluated under the condition that the transmitted polarization is circular.
The relative phase between the two linear E-vectors(E_H,E_V) of the backscattered field is given by

Relative phase $\delta = \arctan(S4/S3)$ $-180 < \theta < 180$ (7)

where the -ve or +ve sign of the phase indicated the rotation direction of the elliptically polarized field (Right or Left).
The ellipticity parameter is represented as
Ellipticity $\chi = -S4/S1$. (8)

Decomposition Methods for Oil Spill Detection

Anne H Schistad Solberg[3][18] has discussed the automatic oil spill detection in her paper. A Neural Networks for oil spill detection using ERS-SAR data was discussed by Fabio Del Frate, Andrea Petrocchi, using the spatial features as input to the Neural Network[2] to differentiate between oil spill and look alike. Images obtained with ERS are with single VV polarization.

The RISAT-1oil spill image near Norway, was acquired in FRS-1 mode with circular transmission and linear reception. RISAT-1[14] FRS1 imaging mode of SAR offers a suitable swath to cover an oil spill area. The Single Look Complex (SLC) product is chosen for further processing, because SLC product includes the real and imaginary part of the image. The Stokes parameter are derived, using SLC image product. From the Stokes parameters, the orientation angle, polarization angle, ellipticity angle and relative phase are obtained. These parameters will vary depending on the dielectric constant of the back scattering material. In RISAT SAR image, it is possible to use phase information, in order to differentiate between oil spill and look alike.

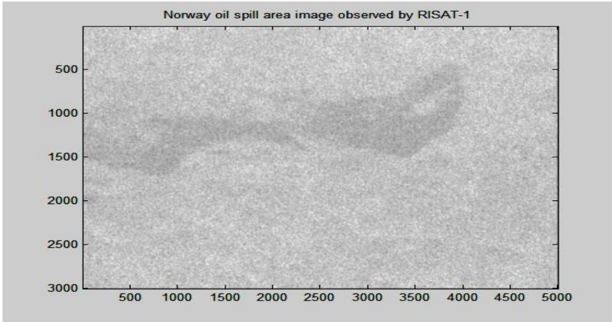

Fig 4: Norway oil spill in V-polarization (RISAT-1 image)

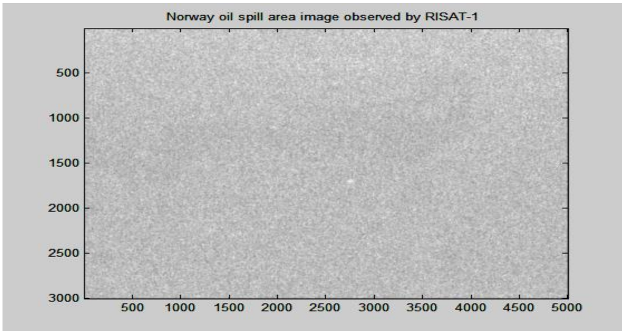

Fig 5: Norway oil spill in H-polarization (RISAT-1 image)

A. Experimental Conditions

On experimental basis, oil was spilled near Norway in the ocean [31] and image was taken through RISAT-1 on 15 June 2012 in FRS-1 mode. This is shown in figures 4 and 5, both in V and H polarization.

B. m-psi or [m-ψ] Decomposition

The degree of polarization parameter m, represented as dp, is chosen as the prime decomposition variable. The orientation parameter Ψ, shown in figure 3, is the second decomposition variable. The orientation angle is derived from RISAT-1 images using Stokes parameter as given in equation 9. The randomly polarized backscatter component is indicated by the degree of depolarization (1-dp).

$\Psi = 0.5 \tan^{-1}(S3/S2)$ (9)

The 'm-psi' decomposition may be expressed through a colour coded image, where

$B = [dp * S1(1 - \sin\Psi)/2]^{1/2}$ (10)

$R = [dp * S1(1 + \sin\Psi)/2]^{1/2}$ (11)

$G = [S1(1-dp)]^{1/2}$ (12)

In this formulation, Blue is sensitive to orientation of -90 degree. Red is sensitive to orientation of +90 degree. Green represents the randomly polarized constituent.

Figure 6a,6b,6c,6d the RGB components and decomposed image for look alike. Similarly figures 6e,6f,6g,6h are the RGB components and decomposed image for oil spill taken by RISAT-1 on June 15, 2012 in FRS-1 mode.

C. m-alpha [m-α] Decomposition

Another method of decomposition is based on the degree of polarization and polarization angle, it is known as 'm-alpha' decomposition. The polarization angle is derived from Stokes parameters and is gives as:

$$\alpha=0.5 \tan^{-1}(\sqrt{(S3^2+S4^2)}/S2) \quad (13)$$

The m-alpha decomposition may be expressed through a colour coded image, where

$$B=[dp*S1(1-\sin(pi/2- 2\alpha))/2]^{1/2} \quad (14)$$

$$R=[dp*S1(1+ \sin (pi/2 - 2\alpha))/2]^{1/2} \quad (15)$$

$$G=[S1(1-dp)]^{1/2} \quad (16)$$

The red colour is sensitive to polarization angle of zero degree, the blue is sensitive to polarization angle of 90 deg. The green is sensitive to dominantly depolarized backscatter.

Figure 7 shows the decomposed image using m-alpha method . Figure 7a,7b,7c,7d are the RGB components and decomposed image for look alike. Similarly figures 7e,7f,7g,7h are the RGB components and decomposed image for oil spill.

D. m-delta Decomposition

The relative phase angle δ is measured between the received two linear polarizations. The relative phase is sensitive to single and double bounce characteristic of the backscattered EM field even in case of imperfect circularly polarized field. The single and double bounce will cause the sign change in relative phase angle δ. The relative phase angle can be selected as alternative to ellipticity angle χ. The degree of polarization and relative phase angle is used for 'm-delta' decomposition.

The m-delta decomposition may be expressed through a colour coded image, where

$$B=[dp*S1(1- \sin \delta)/2]^{1/2} \quad (17)$$

$$R=[dp*S1(1+ \sin \delta)/2]^{1/2} \quad (18)$$

$$G=[S1(1-dp)]^{1/2} \quad (19)$$

$$R^2 + G^2 + B^2 = S1 \quad (20)$$

Figure 8 shows the decomposed image using relative phase(m-delta). Figure 8a,8b,8c,8d are the RGB components and decomposed image for look alike. Similarly figures 8e,8f,8g,8h are the RGB components and decomposed image for oil spill respectively.

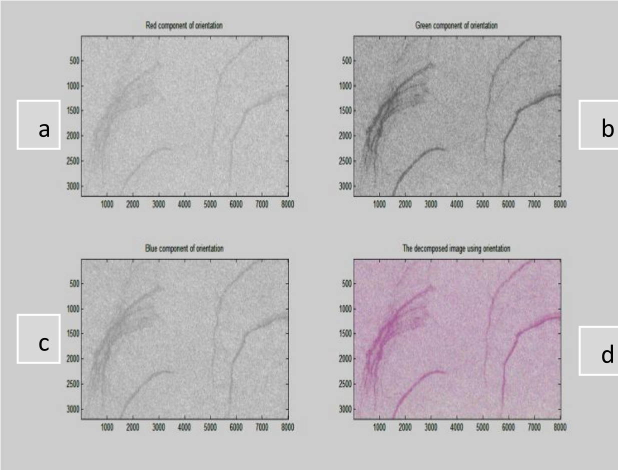

Fig: 6(a),6(b),6(c),6(d) : m-ψ Decomposition of look alikes

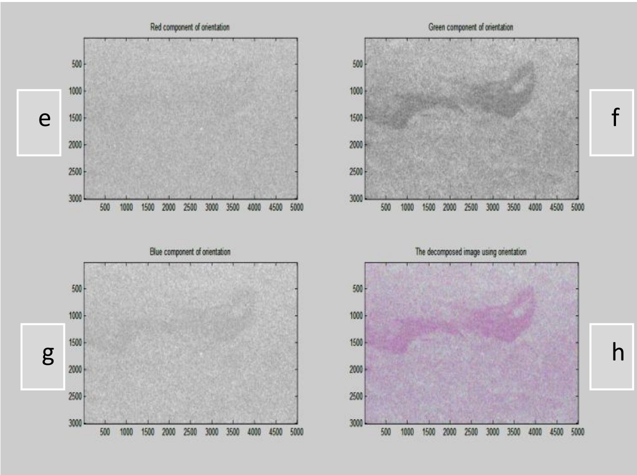

Fig: 6(e),6(f),6(g),6(h) : m-ψ Decomposition of oil slicks

E. m-chi Decomposition

The ellipticity parameter χ represents the circularity of the polarization wave. The sign of ellipticity parameter χ indicates the single or double bounce scatter, irrespective of the EM field is perfectly circular polarized or not. The ellipticity parameter can be selected as second decomposition variable.

The hybrid polarity data can be analysed through m-chi decomposition, which is proven to be excellent analysis tool. The key inputs for decomposition are degree of polarization dp and degree of circularity.

$$\sin 2\chi=-S4/(dp*S1) \quad (21)$$

The colour coded image can be generated using m-chi decomposition using the expression given below.

$$B=[dp*S1(1-\sin 2\chi)/2]^{1/2} \quad (22)$$

$$R=[dp*S1(1+\sin 2\chi)/2]^{1/2} \quad (23)$$

$$G=[S1(1-dp)]^{1/2} \quad (24)$$

In this formulation, Blue indicates single bounce back-scattering. Red corresponds to double bounce, and Green represents the randomly polarized constituent.

Figure 9 shows the decomposed image using m-χ. Figure 9a,9b,9c,9d are the RGB components and decomposed image for look alike. Similarly figures 9e,9f,9g,9h are the RGB components and decomposed image for oil spill.

Observations on the results

The results obtained by implementing the four decomposition methods on RISAT-1 oil slick and look a like images are analysed from two view points for detecting the oil slicks and separatring the look alikes spread out on the ocean surface.

i. Observation of contrast values derived from the images obtained from the four decomposition methods
ii. Observations on the Orientation, Polarization angle, Relative Phase, Ellipticity and total polarised power parameters

i. For all sets of RGB images obtained from the four decomposed methods, average contrast value is computed for the oil slick area, and look alikes against the imaged sea background. The contrast values are plotted and shown in Figures 10, 11 and 12. The red component is found to be useful in isolating the look alikes as can be seen from Figure 10. In general, all decomposition methods are found to be useful in isolating the look alikes from oil slicks. However, m-α decomposition seems to be superior as the red component of the image for oil slick visually disappers whereas look alike patches could be prominently seen. Similarly as seen from Figure 12, m-χ decomposed blue colour image will be useful as the oil slick is poorly visible when compared to look alikes in other decompositions.

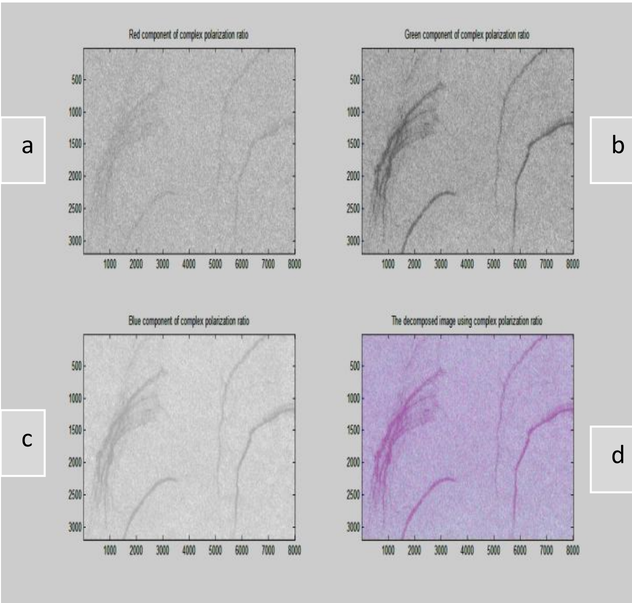

Fig : 7(a),7(b),7(c),7(d): m-α (Pol. angle) Decomposition

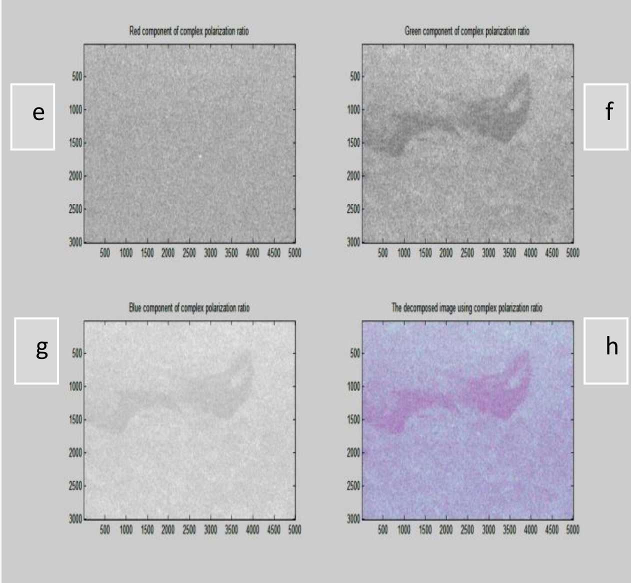

Fig: 7(e),7(f),7(g),7(h) :m-α (Pol. angle) Decomposition

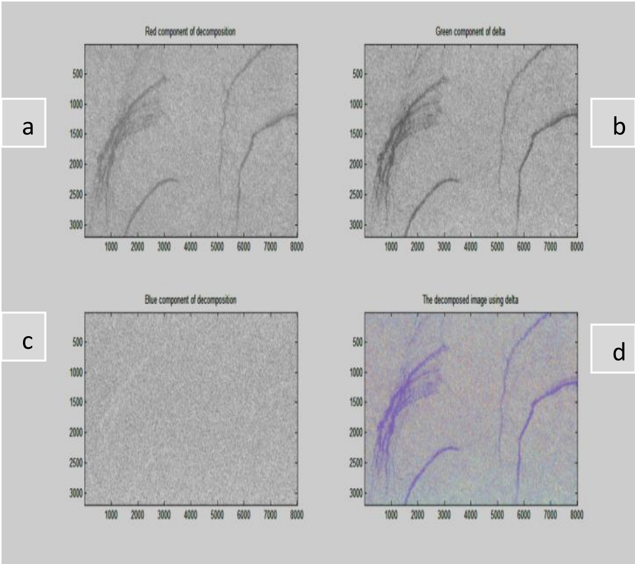

Fig: 8(a),8(b),8(c),8(d) m-δ Decomposition

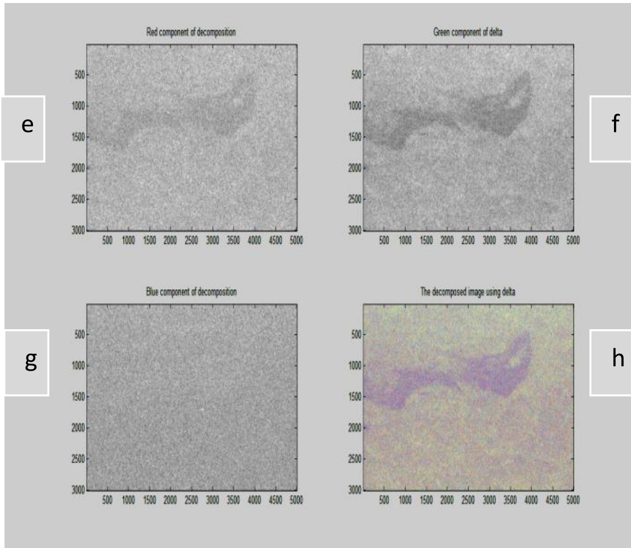

Fig: 8(e),8(f),8(g),8(h) m-δ (Relative Phase) Decomposition

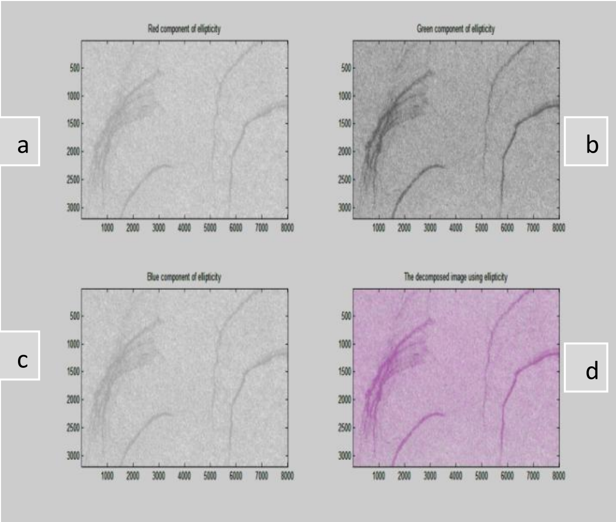

Fig:9(a),9(b).9(c).9(d) m-χ (Ellipticity) Decomposition

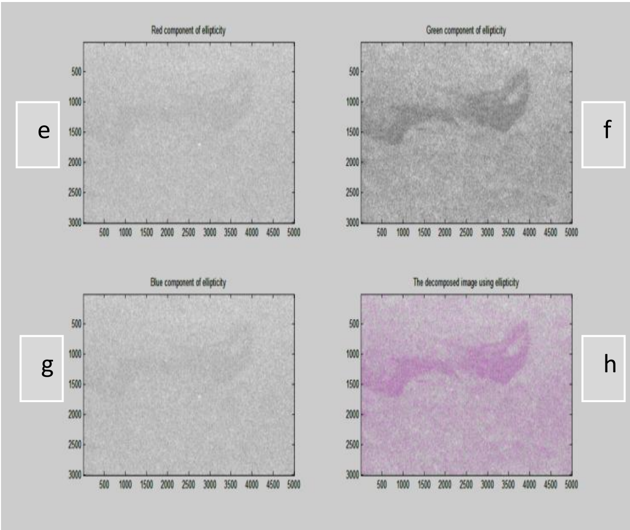

Fig:9(e),9(f),9(g),9(h) m-χ (Ellipticity) Decomposition

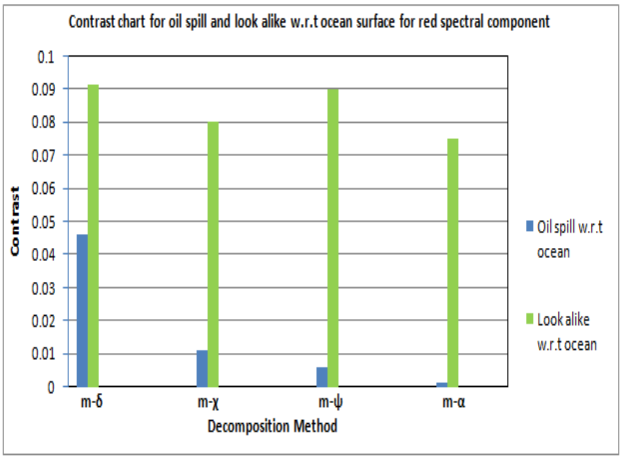

Fig 10: Contrast chart for oil spill and look alikes w.r.t ocean surface for red spectral component

ii. Table 1 gives the values of Orientation, Polarization angle, Relative Phase, Ellipticity and total polarised power parameters for oil slick, look alike and ocean. We can observe that oil spill and look alikes can be discriminated by using orientation angle and relative phase(delta angle) .

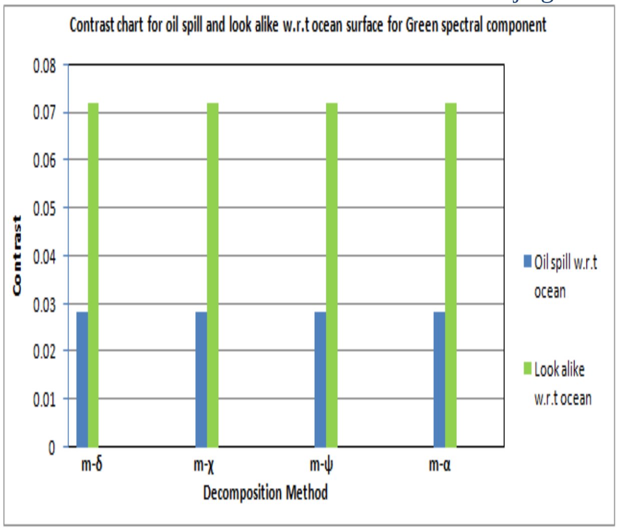

Fig 11: Contrast chart for oil spill and look alikes w.r.t ocean surface for Green spectral component

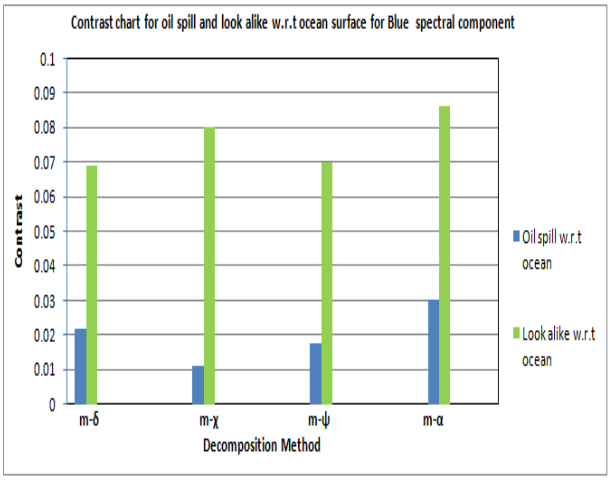

Fig 12: Contrast chart for oil spill and look alikes w.r.t ocean surface for Blue spectral component

Table 1: The comparisons of mean values of delta(deg), Orientation (deg), Ellipticity (deg), degree of polarisation (dp) and total power

	ψ	α	δ	χ	dp	Total Power
oil spill	-0.19	38.9	-0.1	0.00034	0.51	457120
look alike	-3.7	38.3	3.13	-0.00046	0.47	351660
ocean	-1.42	39.5	6.33	-0.00369	0.52	494250

Figure 13 shows the orientation angle for oil spill, look alike and ocean. From this figure we can see that oil spill will give less orientation angle, nearly zero compared to look alike and ocean. Due to the orientation difference we can easily identify the oil spill area from the look alike. Figure 14 shows the delta angle for oil spill, look alike and ocean. From this figure we can see that oil spill will give very less delta angle, nearly zero compared to look alike and ocean, which gives more positive delta angle. Variation in delta value seems to provide an alternate way to identify the oil spill area from look alikes.

Out of the six parameters presented in table 1, two parameters are found to be useful in discriminating the oil slick from ocean and look alikes

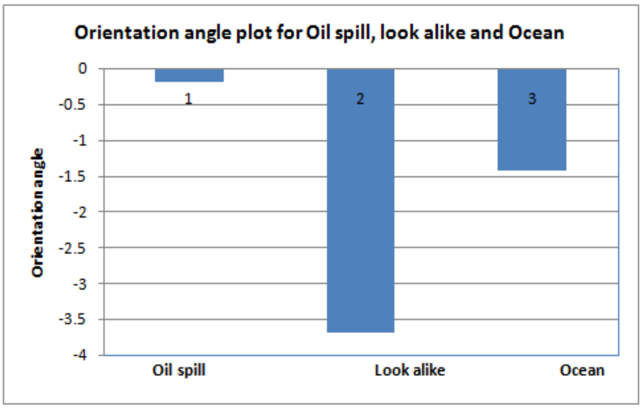

Fig 13: Orientation angle(deg) plot for Oil slick, look alike and ocean

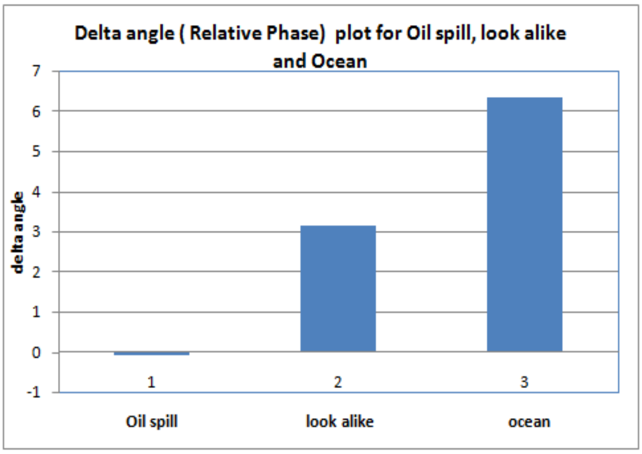

Fig 14: Delta angle (deg) plot for Oil slick, look alike and ocean

Conclusion

RISAT-1 SAR images acquired in hybrid-polarimetric FRS-1 mode are found to be useful for oil spill detection and look alike segregation. The four Stokes parameters are calculated from the received linearly polarized data. The Stokes parameters are used to formulate m-δ (relative phase), m-χ (ellipticity), m-ψ (orientation) and m-α (polarization angle) decomposition of the scenes. The m-δ and m-χ decomposition methods were well proven methods in Chandrayaan-1 mission are applied successfully in this paper for oil spill studies. The m-α and m-ψ methods are additionally attempted in this paper. All the four methods are found to facilitate unambiguous detection of oil spill and discrimination of lookalikes based on unsupervised classification. Orientation angle and relative phase parameters are found to be more suitable for indicators of oil spills and segregation of look a-likes.

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