STUDIES OF OCEAN'S SCATTERING PROPERTIES BASED ON AIRSAR DATA

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KEY WORDS: Polarimetric SAR, Feature extraction, KS test, AIRSAR, Image understanding, Oceans

ABSTRACT:

The scattering properties of ocean are studied based on the measured AIRSAR data in this paper from 3 different sides, which are statistical analysis of sea clutter, the variety trend of polarimetric characters with different incidence angle and ship-sea contrast. The statistical analysis base on KS test shows that the co-pol channels can be fitted well using K distribution under the incidence angles range from 10º to 66º, but the x-pol channel can be fitted well only under a certain narrower incidence angle range. The polarimetric characters show different variety trends with the variety of incidence angles. The entropy of Cloude, co-pol correlation coefficient, co-pol ratio, and the entropy of polarization increase with the incidence angle's increment to the experimental data. But the mean scattering angle and the co-pol phase difference have smaller variety range. From the experimental result, both the microwave band and incidence angle should be considered when we design the threshold of target detection and classification using polarimetric parameters. The ship-sea contrast study at the incidence angle of 46.7º shows that the co-pol correlation coefficient has the highest ship-sea contrast among the researched polarimetric parameters, especially the L band. Moreover, the effectiveness of ship detection based on polarimetric features has the relationship of L>P>C.

1. INODUCTION

It is well known that the Synthetic Aperture Radar (SAR) is well suited to implement continuous (i.e., all-weather, all-time) monitoring of the sea surface conditions and activities, such as surface wind, swell structure, pollution conditions, and the presence of man-made objects, under all-weather condition (Vesecky,2002; Yeremy,2001; Schuler,2004). But the understanding of SAR images is difficult just from the intensity map because the imaging is sensitive to many parameters such as the incidence angle, wind, polarization, wave length and so on. With the development of the polarimetric SAR, besides the RCS information, the scattering mechanism and some other features which reflect the characteristics of targets can be extracted. The study of the scattering properties of ocean clutter is helpful to interpreting the SAR images of ocean and to the design of detection, segmentation, classification, and filtering algorithms.

At present, the study of ocean application based on polarimetric SAR images has been a topic of considerable interest. The backscattering is a kind of random process, so statistical method is used for the description of ocean's scattering. Pastina (Pastina,2000) presented the statistical analysis of multi-frequency, multi-polarization SAR images of the sea surface. His work shows that there is a good agreement between the K-distribution and the statistical properties of the ocean. Fusco (Fusco,2002) also researched the statistical modeling of ocean surface based on the HH and VV channels in the L and C bands of SIR-C data. But the studies about the statistical properties pay attention to the incidence angle hardly.

In the ocean application of polarimeteic SAR, such as pollution monitoring, oil slick detection, ship detection, polarimetric feature extraction is the most important process. Generally the features may vary with the imaging conditions such as incidence angle, imaging band, sea state and so on. The study of features variety trend will be helpful to choose proper features. But this area is still not in focus.

In the work presented here we continue addressing statistical analysis of pol-SAR images of the sea surface based on full polarimetric data under different incidence angles. Moreover, the variety trends of plarimetric features and ship-ocean contrast are studied. Some useful conclusions are gotten by the research.

In this paper, the scattering properties of ocean surface are researched based on the measured polarimetric SAR data, which was acquired by NASA/JPL AIRSAR. Some parameters are shown in the table 1.

Date of acquisition	07/20/1990
Scene ID	Cm1832, Cm1833
Polarization	Quad
Band	C/L/P
Multi-look	16
Range resolution	6.7 m
Azimuth resolution	12.1 m
Wind speed	20 Knots
Wind angle	232 Degrees

Table 1. Radar parameters of experimental data

This paper is organized as follows. Section 2 will study the statistical model of sea clutter using K-distribution. In section 3, the variety trends of polarimetric characters are studied according to different incidence angle. Then, ship-sea contrast based on the polarimetric parameters is studied in section 4. Finally, some useful conclusions are drawn in section 5.

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2. THE STATISTICAL ANALYSIS OF SEA CLUTTER

Plenty of work has been done in the area of statistical analysis of sea clutter. Experimental results（Pastina,2000；Fusco,2002）have shown good agreement between the K-distribution and the statistical properties of the sea radar echoes. In the work presented here we continue addressing statistical analysis of SAR images of the sea surface. And the K-distribution is used to model the sea clutter of different bands, different polarization, especially to the different incidence angles.

2.1 The KS test

It is well known that the k-distribution has the probability density function (PDF) with scale u and order parameter v as follows:

$$p(x)=\frac{4}{x\Gamma(v)\Gamma(L)}\left(\frac{Lvx^2}{\mu}\right)^{\frac{L+v}{2}}K_{v-L}\left(2x\sqrt{\frac{Lv}{\mu}}\right) \tag{1}$$

where L = looks
u = scale of K distribution
v = order parameter of K distribution
$K_{v-L}(\cdot)$ = the modified Bessel function of order $v-L$
$\Gamma(\cdot)$ = Gamma function

To express the goodness-of-fit between K distribution and empirical distribution, the Kolmogorov-Smirnov (KS) test is used (Fusco,2004; Michael,2001)
The KS test is based upon the empirical cumulative distribution function (CDF) of the observed data. The empirical CDF is a piecewise constant function $\hat{P}_R(r)$ that equals zero at $r=-\infty$ and increases by a value of $1/N$ at each observation R_K That is,

$$\hat{P}_R(r)=\frac{1}{N}\left|\{R_K : R_K \le r\}\right| \tag{2}$$

where $|S|$ =the cardinality of the set S
The Kolmogorov statistic, D_{KS} , is defined as the supremum of the magnitude difference between the empirical cumulative distribution function (CDF) and the CDF under H_0 , $Q_R(r)$. That is

$$D_{KS}=\sup_r\left|P_R(r)-Q_R(r)\right| \tag{3}$$

Large observed values d of the statistic D_{KS} suggest evidence that H_0 should be rejected and the probability Pr [$D_{KS}>d$] is reported as the P-value of the test.

2.2 Statistical analysis based on KS test

The experimental polarimetric SAR data is shown in figure 1, where17 areas according to different incidence angles range from 10º to 66º are chosen from the ocean data of C-, L-, and P-band. From top to bottom, the incidence angles of black rectangles are 10º, 13º, 17º and 22º, the white rectangles are 26º, 31º, 37º, 41º, 44º, 48º, 51º, 54º, 57º, 59º, 62º, 64º and 66º, respectively.

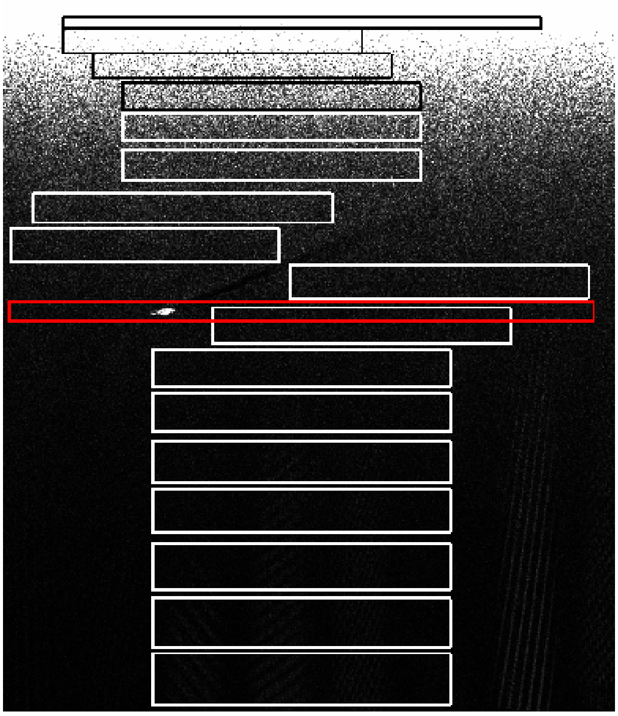
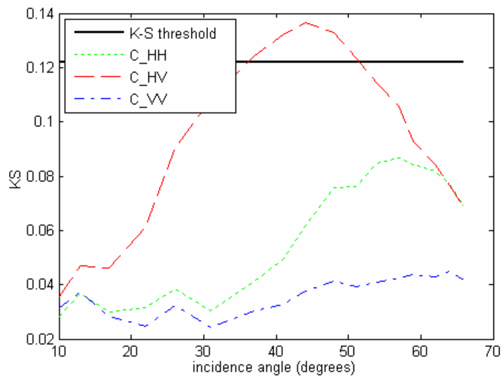


Figure 1. Experimental areas with different incidence angle

To each area, the Histogram can be gotten based on statistical method, and then the KS distance can be computed under the hypothesis of amplitude K distribution. The goodness-of-fit of C-, L-, and P-band under different incidence angles can be shown in figure 2, where the bold black line is the threshold responding to the significance level of α =0.05.



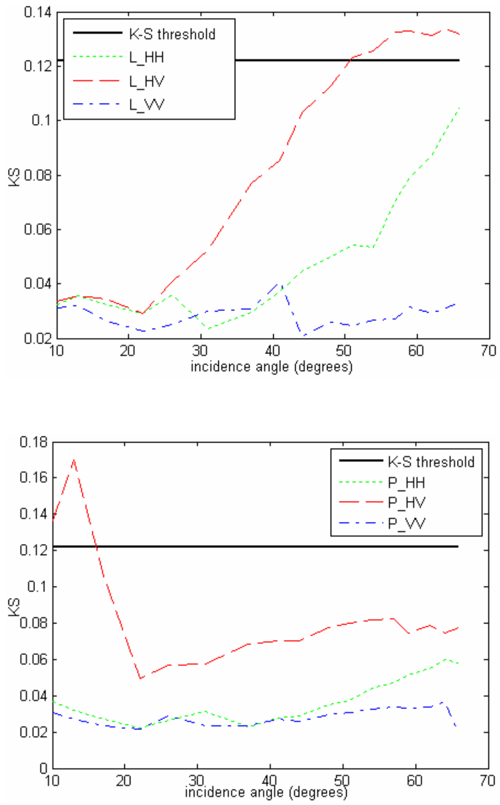


Figure 2. The goodness-of-fit between ocean clutter and K-distribution at different incidence angles (Top: C band; Middle: L band; Bottom: P band)

From the result of figure 2, no matter C-, L- or P-band, the VV channel can get the best fit with the K distribution. Moreover, they are not sensitive to the incidence angle. At the same time, The HH channel, generally, gets satisfied fit, especially under the small incidence angle. But the HV channel gets the worst result, even there are many areas whose KS distance are greater than the threshold value corresponding to the desired significant level, $\alpha = 0.05$. It means that these areas can not be fitted by K distribution. Maybe, the reason is the backscattering is very weak, and it is affected seriously by noise.

3. THE VARIETY TREND OF POLARIMETRIC CHARACTERS WITH THE INCIDENCE ANGLE

3.1 Polarimetric characters

There are many characters can be used to express the scattering properties from different sides. In this paper, we studies the entropy of Cloude (H), the mean scattering angle (a), the co-pol ratio, co-pol phase difference, the extended co-pol correlation coefficient (cor) and entropy of polarization (H_{PE}). They are related with the physics behind scattering process.

The Cloude entropy H and mean scattering angle a are constructed based on the eigen decomposition. The entropy reveals the degree of randomness of the scattering process; the mean scattering angle is related to the scattering mechanism. Their definitions (Cloude,1996) are as follows

$$H = -\sum_{i=1}^{3} p_i \log_3 p_i \tag{4}$$

$$\alpha = \sum_{i=1}^{3} p_i \alpha_i \tag{5}$$

where $p_i = \dfrac{\lambda_i}{\sum_{j=1}^{3} \lambda_j}$

λ = the eigenvalue of the coherent matrix

The co-pol ratio is sensitive to water and can be used for water detection. It can be expressed as

$$r_c = \left| \frac{s_{vv}}{s_{hh}} \right| \tag{6}$$

The co-pol correlation coefficient is reported to be sensitive to surface parameters, and it is defined as

$$\rho_{hh\_vv} = \frac{\left| \langle s_{hh} s_{vv}^* \rangle \right|}{\sqrt{\langle s_{hh} s_{hh}^* \rangle \langle s_{vv} s_{vv}^* \rangle}} \tag{7}$$

Co-pol phase difference is expressed as (8), and it reveals the scattering mechanism, especially, it is effective to separating surface scattering and double-bounce scattering.

$$\varphi_{hh\_vv} = \left| angle\left(\langle s_{hh} s_{vv}^* \rangle \right) \right| \tag{8}$$

The entropy of polarization is related to the depolarization of scattering process, and it defined as follows based on the polarization degree of PD (Bicout,1992)

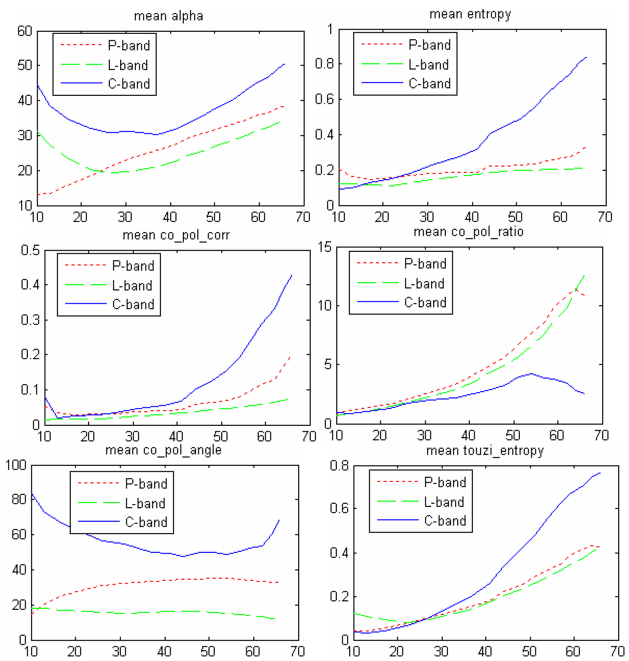
$$H_{PD} = -\ln\left(f(PD)\right) \tag{9}$$

where $f(PD) = 0.5(1+PD)^{0.5(1+PD)}(1-PD)^{0.5(1-PD)}$

3.2 The variety trend of polarimetric characters

To the ocean, some scattering properties will change when the incidence angle changes from 10º to 66º. To study the trend and degree of the variety, we still use the polarimetric data patches shown in figure 1 (except the red rectangle area).

The mean value of each area can be used to describe the variety under different bands and different incidence angles. The variety trends of the polarimetric parameters are shown in figure 3 where the x-label is incidence angle.



Top: scattering angle and Cloude entropy
Middle: co-pol correlation coefficient and co-pol ratio
Bottom: co-pol phase difference and entropy of polarization

Figure 3. The variety trends of polarimetric features under different bands and different incidence angles

Generally, the entropy of Cloude, co-pol correlation coefficient, co-pol ratio, and the entropy of polarization increase with the incidence angle's increment. The mean scattering angle and the co-pol phase difference have different trend among different bands. But their variety range is small; and the maximum variety of alpha is just 8.6º, 11.5º and 17.2º to L, C and P band, respectively. The variety range of co-pol phase difference of L band is just 6.6 degrees. From the experimental result, both the microwave band and incidence angle should be considered when we design the threshold of target detection and classification using polarimetric parameters such as Cloude's entropy, polarization entropy, co-pol ratio, extended co-pol. Correlation coefficient. But if the average angle and the co-pol phase difference are used, the method is robust to incidence angle. Moreover, the parameters variety trends between P-band and L-band are very similar.

4. SHIP-SEA CONTRAST BASED ON THE POLARIMETRIC PARAMETERS

Ship detection in SAR image has been a topic of considerable interest since it has many potential applications within commercial, fishery, vessel traffic, military detection and so on. It is becoming an important branch of ocean application of SAR images. Presently, there are many ship detection methods such as CFAR method, ship wake detection method and so on. Some polarimetric features, related to targets scattering mechanism, can be extracted from Pol-SAR which can be used for ship detection.

Touzi has investigated the ship-sea contrast based on polarimetric SAR images. His work shows that HV channel has higher contrast within the incidence angle of 20º -70º at calm wind conditions (7 knots)(Touzi,2001). In this paper, the ship-sea contrast of typical polarimetric parameters at the incidence angle of 46.7º is studied. The ship and ocean areas are shown in figure 5 which is just a part of figure1 (marked out using red lines). In figure 4, the green rectangles areas are ocean, red rectangle area is ship.

Figure 4. the experimental area used for ship-sea contrast

To express the effect of contrast, we can defined a new parameter as

$$r = \frac{\langle f_{ship} \rangle}{\langle f_{ocean} \rangle} \tag{10}$$

where f_{ship} = ship's feature

f_{ocean} = ocean's feature

Many features can be used for ship detection, and those listed in section 3 are typical. In this paper, they are used to study the ship-sea contrast. Based on the define of (10), the effect of contrast is shown in table 2.

	Alpha	Cloude Entropy	Correlation
P band	4.5388	10.1632	16.6623
L band	6.5328	10.7471	19.8127
C band	2.1463	3.3423	9.0371

	Co_pol_ratio	Co_pol_angle	Entropy
P band	10.0932	8.3536	7.7164
L band	10.9102	15.6778	8.0185
C band	8.4773	2.8755	1.8712

Table 2 ship-sea contrast at the incidence angle of 46.7º and the windy condition of 20 knots (dB)

It can be seen from table 2 that the entropy of polarization is not very effective as that in Touzi's work because of the effect of windy condition (20 knots). The ocean backscatter becomes heterogeneous and the ship-sea contrast by polarization entropy is just 1.7 *dB* , 8.0 *dB* , and 7.9 *dB* to C, L, and P band, respectively. Among the researched polarimetric parameters, co-pol correlation coefficient has the highest ship-sea contrast of 9.0 *dB* , 19.8 *dB* , and 16.7 *dB* to C-, L-, and P-band, respectively. At the same time, the parameter of alpha has the lower/lowest contrast of 2.1 *dB* , 6.5 *dB* , and 4.5 *dB* to the band of C-, L-, and P-band, respectively. The L-band data has better performance of ship detection using the plarimetric parameters compared with the C and P bands. To the experimental AIRSAR data, among the 3 bands, the effectiveness of ship detection has the relationship of L>P>C.

5. CONCLUSIONS

Based on the study of scattering properties to the measured AIRSAR data of ocean, some useful conclusion can be obtained as follows:

1. The ocean clutter of different polarization channel of C-, L-, and P-band can be fitted well using K distribution model, especially when the incidence angle is larger than 20º.

2. Some polarimetric features such as entropy of Cloude, co-pol correlation coefficient, co-pol ratio of VV/HH, and the entropy of polarization increase with the incidence angle's increment; other parameters such as alpha and co-pol phase difference are not sensitive to the variety of incidence angle.

3. Polarimetric features can be used for ship detection. But they have different performances in the same incidence angle of 46.7º. The co-pol correlation is most effective among the researched parameters. Different bands are effective in different level too; L-band data is better fitted for ship detection than P- and C- bands.

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ACKNOWLEDGEMENTS

The authors would like to thank both the NASA/JPL AIRSAR team for the data used in this paper and the National Key Laboratory of ATR for the support to our research (9140C8002010706)