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Qualitative SAR Dark Spot Analysis for Oil Anomaly Characterization

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ABSTRACT

The characterization of the morphology of a dark spot event in a SAR image is crucial to determining the nature, fate and classification of a potential oil on water anomaly. Hence the need to adequately analyze SAR backscatter values from an amplitude power image were darks spots have been identified and extracted. The dark spots are potential areas of oil on water events and it is imperative that they are understood sufficiently for the purpose of assigning the level of confidence in the processing of oil analysis, understanding the type of oil on water event, classifying the extent of weathering impacting the detected anomaly and relating the oil anomaly to a potential source. In order to generate high quality datasets for anomaly characterization, it is imperative to transform satellite image amplitude data into power values in units of dB and represented on a logarithmic scale. This new power dataset is corrected radiometrically and requisite speckle to noise filter applied for data cleaning and noise suppression. Oil anomaly or darks spot extraction, representative of a potential oil on water is event which is the primary objective of the pre-processing is done. Gamma enhancement was applied on the dark spots in order to characterize their radiometric, textural and geometric properties. This is predominantly for estimating the confidence level of each anomaly detected, and their properties which are indicative of the type, fate, age and physical processes relating to each anomaly.

Keywords: Backscatter; Dark Spot; Gamma; Image Processing; Morphology; Oil Anomaly; SAR.

1 Introduction

The characterization of backscatter from SAR images where dark spots have been detected and extracted is key to oil spill detection. Understanding the nature of these dark spots which represent potential oil on water anomalies is a challenge. The nature of SAR oil on water involves determination of the level of confidence the analyst assigns to a detected dark spot. The level of confidence is indicative of how sure the analyst is, in deciding if the dark spot is an oil on water event or a false positive. One key constituent of determining confidence is understanding the morphology of the dark spot backscatter values and relating them to the surrounding ocean clutter for areas without dark spots. This is usually done manually by the analyst, semi-automatically or fully automated using relevant processing software. Typical analysis methods are limited due to the limited range of gray scale values visualized on the dark regions of an oil anomaly. This limitation can be overcome using a Gamma correction in order to increase degree of contrast between the midlevel gray values of SAR backscatter raster dataset. The objective of this is to visualize subtle differences in the anomaly backscatter in order to qualitatively determine the extent of homogeneity of the anomaly, the extent of weathering and biodegradation suffered, the fate, the thickness and geometry of the anomaly. These

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information are key indicators as to the accuracy of a SAR detection and is reflective of the efficiency of the oil spill response and management strategy.

The primary objective of this study is to apply Gamma in a known oil spill event scenario to enhance oil on water characterization. The Shell Nigeria 48" Forcados Export Pipeline which was reported to have suffered severe sabotage damage, spilling crude oil into the ocean is the primary focus area [6] [7] [8]. The volume of oil spill was recorded, but further information which would support pre and post spill response and management is difficult to ascertain from current method. This information includes the understanding the oil fate, extent of weathering, spread and qualitative thickness. Enhanced processing is required to help reveal this information remotely and without obtaining physical oil spill samples.

2 The Existing Processing Methods

The current method of detecting and interpreting oil on water anomaly on SAR datasets involve:

2.1 Radiometric Correction

This process involves SAR calibration for purpose of generating Radar datasets in which the pixel values can be directly related to the radar backscatter of the scene. This involves undoing the processor applied image output scaling and the desired scaling reintroduced. The Sentinel-1A Level-1 product used provide four calibration LUTs to produce ß0i, σ0i and γi(Beta, Sigma and Gamma nought) or to return to the Digital Number (DN). The LUTs apply a range-dependent gain including the absolute calibration constant. For ground range products a constant offset is also applied.

The radiometric calibration is applied by the following equation:

$$\text{value}(i) = |DN_i|^2 / A_i^{\,2} \quad (1)$$

where, depending on the selected LUT,

value(i) = one of $\beta 0_i$, $\sigma 0i$ or γ_i or original DN_i

A_i – one of betaNought(i), sigmaNought, gamma(i) or dn(i)

Bi-linear interpolation is used for any pixels that fall between points in the LUT.

2.2 Speckle Noise Removal

A SAR image is a mean intensity estimate of the radar reflectivity of the region which is being imaged. Speckle noise in SAR is the difference between a measurement and the true mean value of the Radar signal. This is removed through the application of filters to the Radar signal.

Lee Filter: The Lee filter assumes that the mean and variance of the pixel of interest is equal to the local mean and variance of all pixels within the user-selected moving kernel. The Lee filter calculation produces an output value close to the original input value in higher contrast regions and a value close to the local mean for uniform areas. In the latter case a stronger smoothening occurs. The formula for the Lee filter is the following:

Where $DN_{out} = [\text{Mean}] + K[DN_{in} - \text{Mean}]$

Mean = average of pixels in a moving window

$K = \text{Var}(x)/[(\text{Mean})^2 \sigma^2 + \text{Var}(x)]$

$$\text{Var}(x) = [\{(\text{Variance within window}) + (\text{Mean within window})^2\}/[(\text{Sigma})^2 + 1]] - [\text{Mean within window}]^2 \quad (2)$$

Discontinuity Adaptive Prior and Moment Estimation algorithm is to be used to reduce speckle noise SAR images. The stepwise algorithm is as given below:

1) Do the modeling of the original image f(m,n) with probability density function

$$p(f(m,n)/f\wedge(m-x,n-y) = e^{(-log(1+\eta 2(f(m,n),e^{(-log(1+\eta 2(f(m,n),f\wedge))}))} \quad (3)$$

where, $\eta 2(f(m,n),f\wedge \ = \ (1/\rho)2\sum(x,y)\ (f(m,n)\ -\ f\wedge(m-x,n-y))2$

$(x,y)\varepsilon\ \{(0,1),(1,0),(1,1),(1,-1)\}$

2) Do the estimation of mean μ and variance α^2.

3) Incorporate the observed noise model as;

$$X(m,n)/(m,n-1) \ = \ [\mu,1]T \text{ and } P(m,n)/(m,n-1) \ = \ [\alpha 2] \quad (4)$$

4) Calculate sigma points as; X^X

$$Y(m,n)\ /(m,n\ -\ 1)\ =\ x^x\ (m,n)\ /(m,n\ -\ 1) * (m,n\ -\ 1) \quad (5)$$

5) Apply the measurement model on each sigma point.

2.3 Image Processing for Oil Detection

This phase of image processing is primarily for the extraction of events on the ocean surface that can be attributed to oil on water. It involves characterizing true oil slicks and identifying false positives in detection.

2.3.1 DN to dB conversion

To classify water bodies for oil on water detection and get results in terms better contrasts it is imperative to convert the data DN values to Sigma0 dB. Sigma dB is in a logarithmic scale and this enhances the contrast between features and hence improve anomaly detectability.

Radar image brightness is normally expressed in σ0 (sigma nought) which is the radar backscatter per unit area. The unit of σ0 is [m2/m2], expressed in decibel (dB). The standard formula to calculate σ0 is

$$\sigma 0 = 10 * \log 10(DN2) + K \quad (6)$$

Where, DN is the image pixel digital number measured in the SAR image (or more accurately, the average pixel value over a group of pixels). K is a calibration factor which varies depending on the SAR sensor and processor system used.

Where, $\sigma 0$ (dB) – backscattering image in dB

σ0 – Sigma naught image.

Even for homogeneous targets, σ0 varies slightly depending on the angle between the ground and the sensor – the incidence angle – being higher (brighter) in the near-range part of the image (closest to the satellite) and lower (darker) in the far-range of the image, further away from the satellite. By normalizing σ0 with respect to the incidence angle we can remove the range-dependency to obtain γo (gamma-naught):

$$\gamma 0 = \sigma 0/\cos\phi \quad (7)$$

where φ is the incidence angle.

Thresholding is the simplest image segmentation method. During the thresholding process, a threshold value is first set according to certain rules. Pixels are then partitioned into “objects” and “background” according to the threshold. One of major advantages of thresholding method is its simplicity in computation, which can achieve a high speed in segmentation process. An adaptive thresholding method on the image generates dark spots which are potential anomalies. A detecting window is moving through the whole image. The threshold is calculated locally, within the area of a moving window, which is set for dark spots as ΔdBk below the mean value in a moving window. The value of ΔdBk is calculated by the ratio of the standard deviation to the mean value in the local window. The thresholding is combined with a multi-scale approach and a clustering step to effectively separate dark spots from background. Though the thresholding method can achieve fast detecting speed, it may also lead to many false alarms in the process because of speckle noises. Post-processing, such as clustering is usually necessary to eliminate these detected false alarms

2.4 Anomaly Characterization

The Key characteristics in interpreting anomalies are:

Shape: Given the vast area and differing conditions on one image, slicks often stand out because of their shape as they are, generally, not part of the natural environment. Natural oil seeps can 'blend' into the scene dynamics, while non-natural oil releases tend to be more distinct, usually have 2 basic presentations:

1. Long, thin and linear (discharge from moving vessel)

2. Various sizes – but regular shape, and emanating from a point source (discharge from oil production facility or stationary vessel)

They can be Linear, Plume, Pear or oval, Comb, Horse Shoe, Irregular or Feathering.

Size: Knowledge of area (ideally gained through local experience, or from repeated observations) will give an indication of the types of oil present in the region, and hence the likely size of such events. An example is ship sources (moving) oil releases typically in the 100's to 1000's of meters in width but can be tremendously long (over 100 kilometers). Platform releases tend to be smaller, possibly 10's of kilometers in size, various widths (can be linear or circular).

Contrast: In otherwise homogeneous environment, the most obvious detection of a potential anomaly is depicted by large contrast from surrounding 'gray levels' in the area around the potential oil. Contrast is based on a multitude of factors and this makes the creation of "signature" libraries based solely on contrast very difficult (and hence, makes automation even more of a challenge). Over time the contrast will become less due to several phenomena such as weathering, biodegradation and evaporation which break down the slick. Thickness, oil type and concentration also play a key role in slick appearance and this is very difficult to quantify. Near-range/far-range location of slick in the image – near-range slicks should appear darker than far range

Context: This is probably the most powerful determinant of the confidence of the analysis. The situation in the surrounding environment / conditions in the area, have a large influence on interpretation. Details of the slick edge can add a time element (start-end of slick), and when coupled with wind direction provide morphology information. Targets in the area of a potential slick are also significant pointers but should not 'force' decision. The presence of other oil-like signatures in proximity to a potential spill source is a positive indicator [10].

3 The Gamma Correction Method

3.1 Image Gamma

Gamma refers to the degree of contrast between the midlevel gray values of a raster dataset. Gamma correction primarily does not affect the black or white values in a raster dataset, only the middle values. In applying a gamma correction, overall brightness of a raster dataset is controlled. Gamma values less than one decrease the contrast in the darker areas and increase the contrast in the lighter areas. This darkens the image without saturating the dark or light areas of the image. This helps bring out details in lighter features, such as a detected oil on water anomaly [8].

The relationship between the input and output is that the output is proportional to the input raised to the power of gamma. The formula for calculating the resulting output is as follows [9]:

$I' = 255 \text{ x } (1/255)^{y}$

Below is representative of a pseudo-code performing gamma correction:

gammaCorrection = 1 / gamma

colour = GetPixelColour(x, y)

newRed = 255 * (Red(colour) / 255) ^ gammaCorrection

newGreen = 255 * (Green(colour) / 255) ^ gammaCorrection

newBlue = 255 * (Blue(colour) / 255) ^ gammaCorrection

PutPixelColour(x, y) = RGB(newRed, newGreen, newBlue)

The primary objective of Gamma for this study is to improve the visual representation of radar anomaly in order to enhance anomaly characterization.

3.2 Datasets and Materials

SAR Datasets - The radar datasets used are Sentinel – 1A SAR datasets acquired between 18th November 2016 to 29th January 2017 [2], when there were reported oil spill events around the offshore section of the forcados oil field of the Gulf of Guinea, Nigeria. Four SAR images were used and analyzed. Below are the image details:

Table 1. SAR datasets used and their satellite properties.

S/N	Image Name	Polarization	Product Type	Mode	Incidence Angle_Near	Incidence Angle_Far
1	S1A_IW_GRDH_1SDV_20161118T175244_20161118T175313_014000_0168F2_DDF0	VV	GRD	IW	30.768 deg	45.967 deg
2	S1A_IW_GRDH_1SDV_20161212T175244_20161212T175313_014350_0173EE_A50B	VV	GRD	IW	30.769 deg	45.957 deg
3	S1A_IW_GRDH_1SDV_20170105T175242_20170105T175311_014700_017EAF_270C	VV	GRD	IW	30.768 deg	45.957 deg
4	S1A_IW_GRDH_1SDV_20170129T175241_20170129T175310_015050_018977_5247	VV	GRD	IW	30.768 deg	45.957 deg

Image Processing Tools - The specialized resources used for processing, analysis and interpretation are Images processing. Image Processing Tools - SNAP toolbox software, ENVI Image processing software are used for Radar image processing and analysis, ranging from pre-processing to oil on water detection. While ESRI ArcGIS 9.0 (arcInfo license) for GIS spatial analysis and data integration.

4 Enhanced Visualization Experiment

In order enhance characterization of detected oil spill anomaly, the Gamma enhancement is applied at various scales to the detected dark spots. This was instrumental in extracting the radiometric properties of the detected anomaly. Below are the radiometric properties of interest:

Object Backscatter Mean (OMEAN) [dB]: The mean of the backscatter values of the dark object pixels indicative of a possible oil spill.

Object Backscatter Standard Deviation (OSD) [dB]: The standard deviation of the backscatter values of the dark object pixels indicative of a possible oil spill.

Background Backscatter Mean (BMEAN) [dB]:The mean of the backscatter values of the values of the pixels in the enclosing rectangle around dark object representative of the ocean backscatter.

Mean Contrast (MeanC) [dB]: This is the difference between the mean background backscatter and the mean object backscatter.

Max Contrast (MaxC) [dB]: This is the difference between the maximum background backscatter and the minimum object backscatter.

Standard Deviation Ratio (SDR): Defined as the ratio of object standard deviation to background standard deviation.

Mean Ratio (MR): Ratio of object mean backscatter to background mean backscatter

4.1 Anomaly Processing Results

In this study, Gamma enhancement of between 1.9 – 2.05 was applied on the SAR power converted datasets which have identified anomalies. This increased contrast level of the backscatter values enhanced the extraction of the geometric and radiometric properties of the identified anomalies these discriminating their fate, extent of weathering, qualitative thickness, morphology and size.

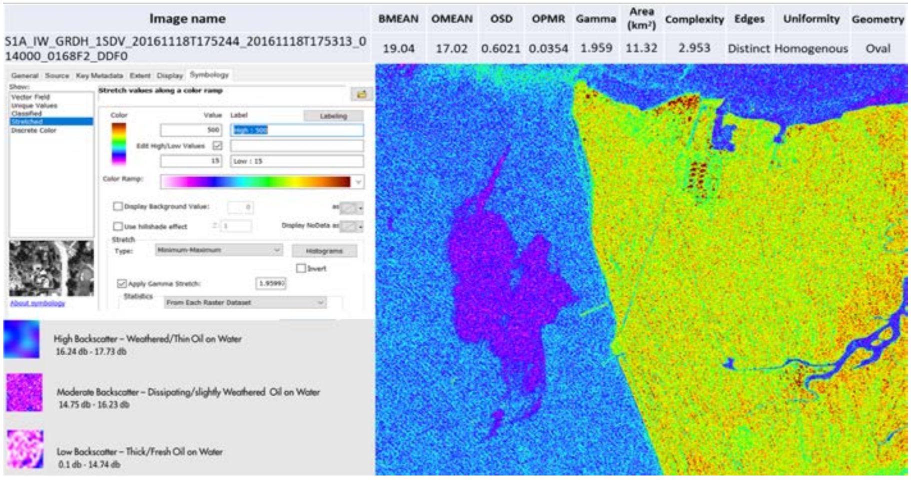

Figure 1: Experimental results of SAR detected anomaly on 18th of November 2016

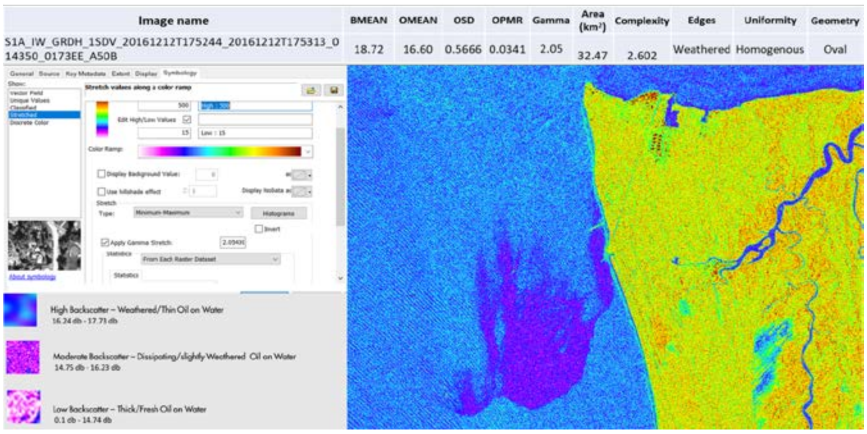

Figure 2: Experimental results of SAR detected anomaly on 12th of December 2016

Image name	BMEAN	OMEAN	OSD	OPMR	Gamma	Area (km²)	Complexity	Edges	Uniformity	Geometry
S1A_IW_GRDH_1SDV_20170105T175242_20170105T175311_014700_017EAF_270C	19.14	17.04	0.7119	0.0418	2.02	36.67	3.681	Weathered	Heterogenous	curvilinear

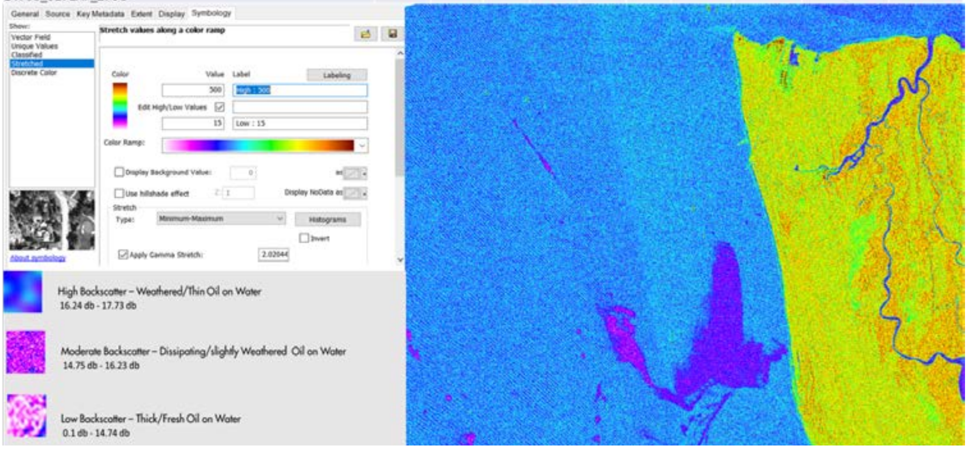

Figure 3: Experimental results of SAR detected anomaly on 5th of January 2017

Image name	BMEAN	OMEAN	OSD	OPMR	Gamma	Area (km²)	Complexity	Edges	Uniformity	Geometry
S1A_IW_GRDH_1SDV_20170129T175241_20170129T175310_015050_018977_5247	19.43	17.20	0.5624	0.0327	1.998	2.01	2.060	Weathered	Heterogenous	Angular

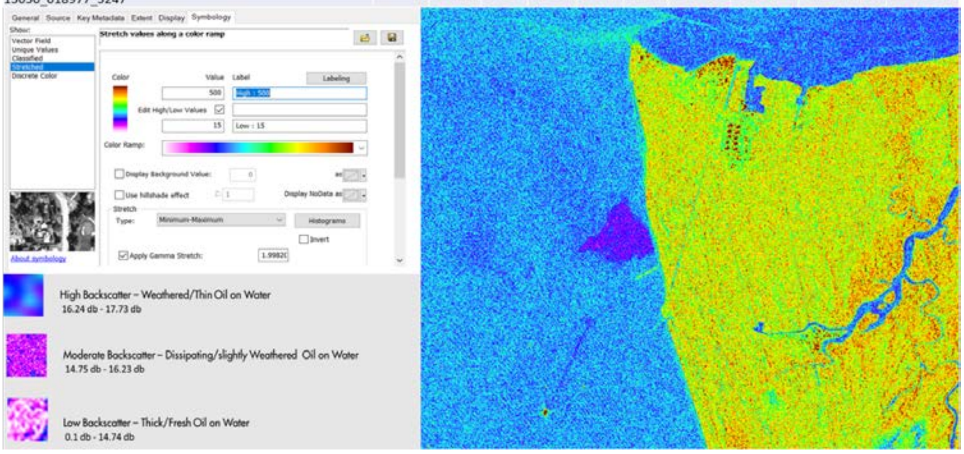

Figure 4: Experimental results of SAR detected anomaly on 29th of January 2017

It can now be clearly visualized that the first identified oil on water event (fig.1) is most probably thick, unweathered, homogenous with minimal spreading and dissipation. The oil event can be seen to gradually weather, dissipate and reduce in size as it progresses from Fig.2 to Fig.3. At Fig 4. significant weathering has occurred, and the anomaly has become more heterogenous and reduced in size.

Figure 5: Part of spill impact on 48” Forcados Export Terminal Export Pipeline at Ogulagha. Picture was taken during overfly on 10th November 2016. (Source: SPDC JIV Report Incident 1747111)

5 Conclusion

In this study, we demonstrated the use of Gamma in extending the contrast spectral range of the detected anomaly. Extending contrast range of anomalies clearly revealed the degree of homogeneity, level of weathering, fate and the geometry of detected anomaly around the oil spills observed along the Shell Forcados Export pipeline. This helped in characterizing SAR backscatter into weathered, thick, thin, dissipating, oval or linear oil spill anomalies. Low backscatter features are related to homogenous, thick and fresh oil, and the converse applies to high backscatter features. This methodology has been able to demonstrate that Gamma correction is key to aiding interpretation in deciding if a detected anomaly is a false oil positive or an actual oil spill event. There was significantly close correlation between information on texture, geometry observed between high definition optical photography of the spill and Gamma enhanced SAR data. Gamma gives very strong representation of the radiometric properties of a detected anomaly. There is however more scope for future work for improving interpretation of SAR datasets using more filters, stretch methodologies and more advanced algorithms.

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