AN ALTERNATIVE APPROACH FOR CALCULATING THE SAR DAMPING RATIO OF VERIFIED OIL SLICKS

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ABSTRACT

The damping ratio is a calculated feature that measures the contrast between oil-slicked water and the open ocean in SAR data. To implement the damping ratio, the current literature suggests estimating the open water backscatter by taking strips of undefined width across the range direction, obtaining the damping ratio as a function of incidence angle. We show in this paper that the method proposed in the literature can be improved by instead sampling open water pixels randomly. The method is tested on RADARSAT-2 quad-polarimetric SAR imagery of a verified oil slick acquired during the 2013 NOFO oil-on-water exercise conducted in the North Sea. The results suggest that deviations in the derived damping ratio encountered by implementing the method proposed in the literature can be reduced from of order 10^0 – 10^{-1} to 10^{-3}.

Index Terms— RADARSAT-2, oil spill, damping ratio

1. INTRODUCTION

Spaceborne synthetic aperture radar (SAR) is currently used operationally for marine oil slick detection and other ocean surveillance purposes. A significant issue with spaceborne SAR instruments is that currently they only operate in one frequency band restricting the amount of polarimetric information that can be retrieved in contrast to systems that operate in multiple frequency bands. In addition, information from only one polarimetric channel (either the VV or HH channels) may be usable due to noise limits of the sensor.

When significant amounts of oil are discharged onto the ocean surface, either accidentally or illegally, accurate information locating the thickest oil in the slick is needed to direct clean-up efforts. Identifying zones by relative thickness within a slick is especially desirable and constitutes an active area of current research. Given the size in surface area oil spills can reach on the ocean surface, spaceborne SAR has proved to be an invaluable asset for characterization in recent years.

A well-known approach for determining information in regards to the relative thickness of an oil slick is by determining the oil slicks damping ratio (DR) [1] - [6]. The DR measures the contrast between the radar backscatter of pixels within an oil spill and the surrounding open water areas. Mathematically the DR is given as

$$DR_{TR}(\theta) = \frac{\sigma_{TR}^{0,sea}(\theta)}{\sigma_{TR}^{0}(\theta)} \qquad (1)$$

σ_{TR}^{0} indicates the normalized radar cross-section (σ^0) for the transmit (T) and receive (R) polarimetric channel of the SAR (TR typically denotes either the VV or HH polarimetric channels), θ is the incidence angle, and $\sigma_{TR}^{0,sea}$ is the radar cross section from clean, open water, external to the oil slick, which needs to be estimated.

An extensive literature review has been conducted and it was determined that there is little explicit information on how to calculate $\sigma_{TR}^{0,sea}$. The few studies that provide a method for calculating $\sigma_{TR}^{0,sea}$ include [1], [2], [3], [4], [5], [6].

In these studies, a strip of an undetermined thickness running in the range direction is extracted from the open water pixels in the vicinity of the slick. The pixel values are averaged across the azimuth direction for every point in the range direction resulting in a profile that has a length the same as the scene in the range direction. A polynomial fit is then applied to the resultant profile.

In this paper we show that the proposed method can lead to ambiguities in DR values depending on where within the image the strip is extracted, and compare the retrieved DR values to DR values from another method that is less complex to implement. The reduction in complexity is due to the fact that extracting strips across the range direction necessitates that large areas of open water be present in the vicinity of the slick, which may not always be the case depending on the severity of the oil spill event and the extent of the SAR image. An alternative method is outlined in Section 2.1.

It should be stated that consistent DR values are desirable as certain algorithms, such as those proposed by [5], rely on the pixel-by-pixel change in SAR-derived feature values from time-series data. Inconsistencies in derived DR values from multiple acquisitions can alter the final product.

2. DATA

The Norwegian Clean Seas Association for Operating Companies (NOFO) performed its annual oil-on-water exercise in the North Sea (N 59° 59', E 2° 27') on 11 June 2013. Throughout the exercise, controlled discharges of oil and biogenic simulator were used to test clean-up methods as well as to test response procedures. The exercise provided a rare opportunity to acquire SAR data of verified plant and mineral oil slicks simultaneously. The mineral oil slick was subjected to mechanical recovery before the SAR imagery was acquired while the plant oil was left untouched. The data was acquired by RADARSAT-2 (a C-band SAR sensor) in fine quad-polarization mode.

Table 1 provides relevant information about the SAR acquisition and wind speed measurements taken from ships participating in the exercise. There is a difference in time and space between the acquisition of the wind speed data and the acquisition of the SAR data, however large deviations from these measurements are not anticipated.

Fig. 1 shows the SAR acquisition acquired on 11 June 2013. Two slicks can be observed within the scene. The first is plant oil that was released approximately 3 hours prior to the SAR acquisition and the other of mineral oil emulsion released approximately 1 hour prior to acquisition.

Table 2 provides relevant information regarding the discharged oil.

Table 1: Properties of SAR scene [7].

Date	11June 2013
Time (UTC)	17:18
Mode	Fine Quad.
Incidence angle	28.1° - 29.9°
Resolution (Rg x Az) [m]	5.2 x 7.6*
Pixel spacing (Rg x Az) [m]	4.7x 4.8
Wind speed	5 m/s

* Nominal value for Fine-Quad mode [8].

2.1. Deriving the Damping Ratio from SAR imagery

Two methods for deriving the DR will be investigated in this paper. The first, is the method outlined in Section 1 and which is highlighted in the literature, whereby strips of open water pixels are extracted from open water areas adjacent to the slick. These strips can be seen in Fig. 1 and are 500 pixels in width in the azimuth direction. Each individual strip is labeled S1 to S5 for reference.

The second method involves masking out the oil-slicked areas of the image and then randomly selecting open water pixels in the azimuth direction for each point in the range direction. In this study, the masks separating the oil infested areas from open water were manually created. The randomly selected pixels are then averaged resulting in a profile that has a length the same as the scene in the range direction. In a similar vein to the previously outlined method, a polynomial fit is then applied to the resulting profile.

Table 2: Time of release of oil and operations performed between discharge and the time of satellite acquisitions. Age of the spills as observed in SAR imagery is also displayed. Taken from [9].

	Date (time of release)	Vol. (m^3)	Subjected to	Age [hours]
Emulsion	11 June 2013 06:00	50	Mechanical recovery (~ 14 m^3 left on surface)	1
Plant oil	11 June 2013 14:00	0.4	Untouched	3.5

In this paper, the random selection of 500 pixels was performed 5 times and for each incidence angle bin (in the range direction).

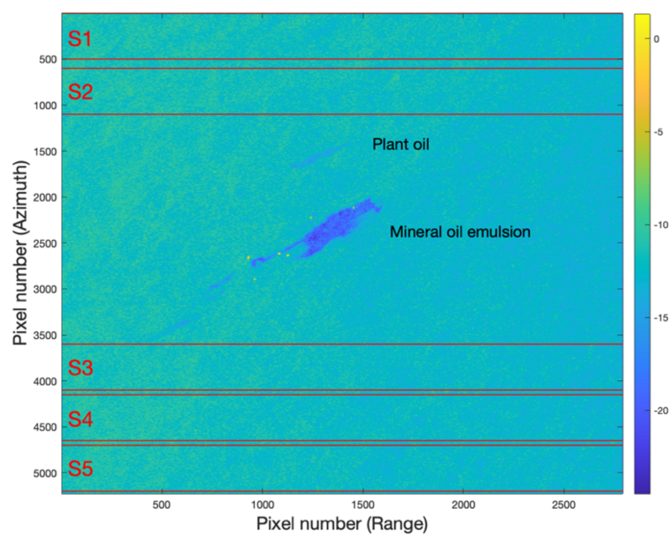

Fig. 1: Intensity image ($\sigma^0_{VV}[dB]$) of Radarsat-2 scene acquired on 11 June 2013, 17:18 UTC, multi-looked by 9x9 window.

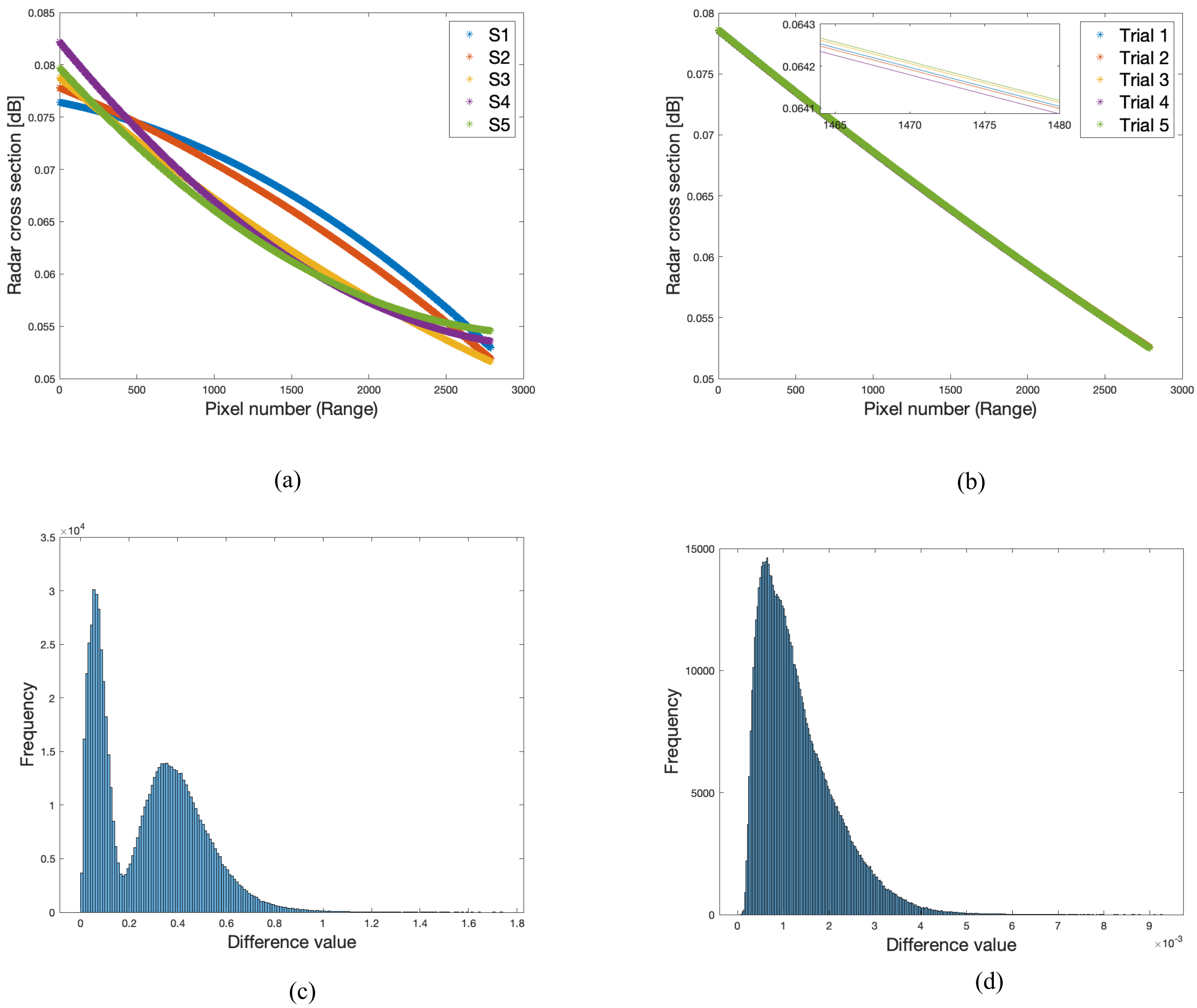

Fig. 2: (a),(b) Polynomial fits for the averaged profiles which were generated by taking strips of open water pixels and by randomly sampling the open water pixels respectively. The polynomial fits act as estimators for $\sigma_{TR}^{0,sea}$ (the numerator in (1)). (c),(d) Histograms for the difference images. As can be seen, a greater degree of error is incurred by estimating $\sigma_{TR}^{0,sea}$ using strips of open water pixels.

3. RESULTS

Fig. 2 shows the results of calculating the damping ratio for the scene shown in Fig. 1. Fig. 2 (a) and (b) show the fitted profiles representing $\sigma_{TR}^{0,sea}$ for the case of the 5 strips, S1 – S5, and the randomly drawn pixels respectively. As can be seen, the fitted profiles for the randomly drawn pixels in Fig 2 (b) are more consistent between trials than the fitted profiles derived using strips of open water open ocean pixels. The insert seen in Fig. 2 (b), which displays a zoomed in portion of the profiles, demonstrates the high degree of overlap between profiles.

In order to compare retrieved DR values, the open water pixels in the derived DR images were masked out and only the DR values for the pixels within the mineral oil slick area considered. For cases where the DR values were calculated by extracting strips of open water pixels and for extracting pixels randomly, 5 DR images were generated.

To compare the derived DR values within each method and to test the consistency of the derived results, a series of difference images were generated. A difference image in this study indicates where the absolute value of the DR values generated from one strip or random trial is subtracted from the DR values generated from other strips or random trials. The result is 10 difference images generated for both methods each.

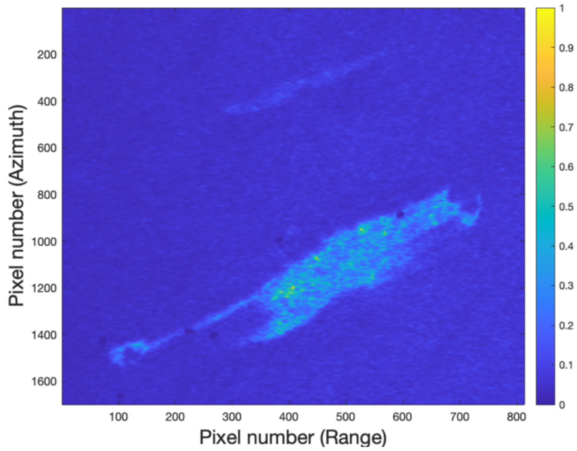

Fig. 3: Image showing a difference image calculated by using the DR derived from strip S1 (as seen in Fig. 1) subtracted from the DR derived by random sampling.

Fig. 2 (c) and (d) show the histograms for both set of difference images for the strip method and random method respectively. The histograms were generated from the difference values in all 10 difference images for the two methods.

As can be seen, difference values for the DR values when calculated using the strip method are on the order of $10^0 - 10^{-1}$. Difference values for the DR values when calculated randomly are on the order of 10^{-3}. In addition, two peaks can be observed in Fig. 2 (c). This is a result of estimations for $\sigma_{TR}^{0,sea}$ being similar to one another. This can be seen in Fig. 2 (a) where estimations for $\sigma_{TR}^{0,sea}$ for S1 and S2 differ to the estimations for S3, S4 and S5, which are also nearly identical. In contrast, no such occurrence can be observed in the histogram in Fig. 2 (d).

Fig. 3 shows a difference image calculated by using the DR derived from strip S1 (as seen in Fig. 1) subtracted from the DR derived by a trial of random sampling. As can be seen, the differences in derived DR values within the mineral oil slick can in some cases reach values of 1 between the two methods. While this may not be significant if a relative indication of thickness is required for a single acquisition, errors can be significant if a stability analysis using time series data is required.

4. CONCLUSIONS AND FURTHER WORK

As can be seen, methods for calculating the DR as presented in the literature may not be appropriate as inconsistencies in the retrieved results can occur. In this study we have introduced another method for calculating the DR that relies on estimating the backscatter from open water by randomly selecting pixels external to the oil slick. This procedure appears to produce more consistent results than sampling by using strips of open water.

One desirable outcome for the calculation of the DR is that retrieved values are consistent and are independent on where within the scene $\sigma_{TR}^{0,sea}$ is determined. As already stated, this is highly relevant when conducting an oil slick stability analysis [5] due to errors that may compound from discrepancies in derived DR values over many scenes in a time series.

Further work will focus on investigating other methods for calculating the DR as well as the effect the proposed method in the literature has on retrieving relative thickness estimations in addition to the absolute estimations for the DR. Further work will also focus on investigating discrepancies that may occur in multifrequency SAR data of verified oil slick by using the strip method outlined in this paper.

6. REFERENCES

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