# A COMPARISON BETWEEN OIL-TO-WATER VOLUMETRIC FRACTIONS DERIVED FROM L-BAND SYNTHETIC APERTURE RADAR IMAGERY AND IN SITU SAMPLES

*Cornelius Quigley[1], A. Malin Johansson[1], Cathleen E. Jones[1,2], Oscar Garcia-Pineda[3], Frank Monaldo[4,5]*

[1]UiT – The Arctic University of Norway, [2]Jet Propulsion Laboratory, California Institute of Technology, [3]Water Mapping LLC, [4]University of Maryland, [5]National Oceanic and Atmospheric Administration

## ABSTRACT

We compare in-situ water volume measurements of mineral oil emulsion sampled from an oil slick in Santa Barbara, California, to acquisitions of airborne UAVSAR data acquired in June 2022. Estimating the water-to-oil fraction using the UAVSAR imagery, we find that low SNR in the co- and cross-polarimetric channels limits this capability above a certain oil-to-water volumetric threshold. Higher SNR regions of the slick had water volume fractions below 20%, while lower SNR regions had water volume fractions above 20%. Calculated damping ratio values align with the noise analysis, indicating that a lower SNR corresponds to higher damping values, while a higher SNR corresponds to lower damping ratio values. For the high SNR case, water fractions calculated using the co-polarimetric ratio (VV/HH) and a theoretical backscattering model were slightly underestimated when compared with in-situ measurements. This observation could be due to potential sampling bias during the collection of in-situ samples, favoring thicker oil with a higher water cut.

***Index Terms—*** Dielectric properties, oil spill, surface slick characterization, synthetic aperture radar (SAR)

## 1. INTRODUCTION

When major oil spill events occur, relevant geophysical information related to the spilt oil is sought to aid clean-up operations. These include the location of the discharge, the physical distribution of oil on the ocean surface, the location of thicker oil in the slick, and the volume of oil present [1, 2].

This study delves into the potential application of low noise, quad-polarimetric Synthetic Aperture Radar (SAR) data for estimating the oil-to-water fraction of a verified oil slick on the ocean surface. The primary objective involves comparing the retrieved oil-water fraction values from SAR with in-situ measurements to assess their accuracy and reliability.

Previous studies have investigated the water content of oil emulsions on the ocean surface, specifically the oil-to-water volumetric ratio, for remote sensing applications [3, 4], where [4] determined that the oil-to-water fraction can be inferred from SAR. Using the co-polarimetric ratio (VV/HH) derived from C-band Radarsat-2 data of verified oil slicks off the coast of Norway and a polarimetric two-scale model [5] determined the in-slick dielectric constant which changes depending on the oil-to-water mixing fraction. Although no in-situ data were reported by [5], their derived values for the dielectric constant agreed with theoretical estimates. In a follow up study using both the co- and cross-polarimetric ratios (HV/VV) from Deutsches Zentrum für Luft- und Raum-fahrt (DLR) low-noise floor, multi-frequency airborne F-SAR data (X-, S- and L-bands) [6], the researchers found that the parts of the slick that showed the lowest dielectric values (oil emulsions with lower water volume fractions) corresponded well to values derived using only the co-polarimetric ratio.

We make use of data acquired by the National Aeronautics and Space Administration (NASA)'s L-band Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) at the Coal Oil Point seep field near Santa Barbara, California, in June 2022. This dataset includes a unique set of in-situ data, comprised of multi-spectral aerial drone imagery, oil-to-water volumetric measurements, and continuous imagery from GoPro units fixed to the boat. Fig. 1(a) shows a VV UAVSAR image of a small portion of an oil slick, the corresponding oil slick as seen by a remote-controlled aerial drone (Fig. 1(b)), a photograph of the same slick taken from the boat (Fig. 1(c)), and oil samples collected from the ocean surface (Fig. 1(d)). In total, five UAVSAR flights were made on five separate days in June-July 2022.

In this study, attention is directed towards the data collected on June 27. A total of 14 quad-polarimetric scenes were acquired over the course of 4 and a half hours, with an approximate time interval of 16 minutes between each acquisition. To gather oil/water volumetric fractions, manual sampling was conducted at five randomly selected study sites, which are described in Section 2. The sampling was approximately synchronized with five specific UAVSAR acquisitions, as presented in Table 1.

This paper also compares the sampled oil-water fraction values with the calculated damping ratio (DR) imagery derived from the five UAVSAR scenes. The DR, believed to be associated with the thickness of an oil slick, is computed

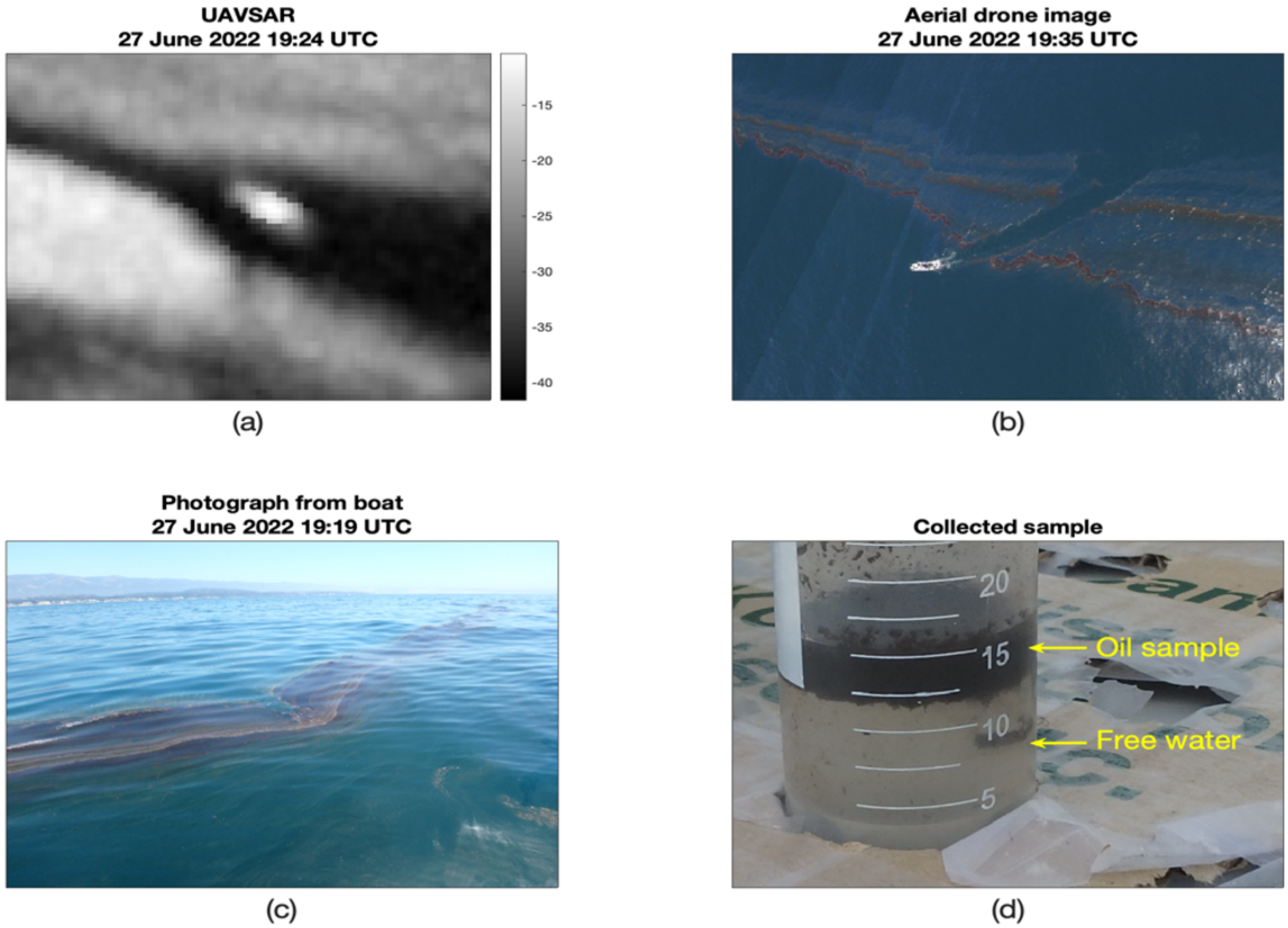


**Fig. 1. (a) VV UAVSAR intensity image in dB showing the oil slick. The boat can be seen as a bright spot within the slick. (b) Multispectral drone imagery showing the oil slick area as well as the boat. (c) Photograph of the oil slick taken from the boat. (d) Example of test tubes, acquired on June 28, 2022, showing collected samples of oil before de-emulsifier was added. The oil/water sample as well as free water can be seen.**

using the algorithm described in [7]. Through this analysis, this study aims to demonstrate the relationship and potential correlations between the oil-water fraction and the DR.

## 2. DATA COLLECTION

On June 27, 2022, five sites were chosen for acquiring in situ measurements based on the visual appearance of the oil observed from the boat. Notably, preference was given to oil exhibiting a thick, viscous appearance, which facilitated its convenient collection for subsequent analysis. Examples of this can be seen in Fig. 1 (b) and (c). At each site, five oil samples were collected and placed into individual test tubes, each with a total volume of 50 ml. The collected samples consisted of a combination of oil, either pure mineral oil or mineral oil emulsion, and free water obtained during the sampling process from the surrounding seawater. An illustration of such a sample is shown in Fig. 1 (d).

The combined volume of oil and free water in each sample, denoted as $a$, along with the volume of free water alone, represented as $b$, were recorded. Subsequently, approximately 15 drops of an industrial demulsifier (Alcopol O 60%) were added to the collected samples in the test tubes. The test tubes were then vigorously shaken for 20 seconds to ensure thorough distribution of the demulsifier throughout the sample. Following shaking, the test tubes were left undisturbed for approximately 20 minutes to allow the emulsion to separate. After separation, the total volume of water in the test tube, denoted as $c$, was measured. The fraction of water entrained in the oil sample is then determined as follows:

$$f_{water} = \frac{b-c}{a-b} \tag{1}$$

Table 1 presents the water fraction results along with the corresponding environmental conditions under which they were acquired. It is important to note that in certain instances, water fraction values are absent. This occurs when it was

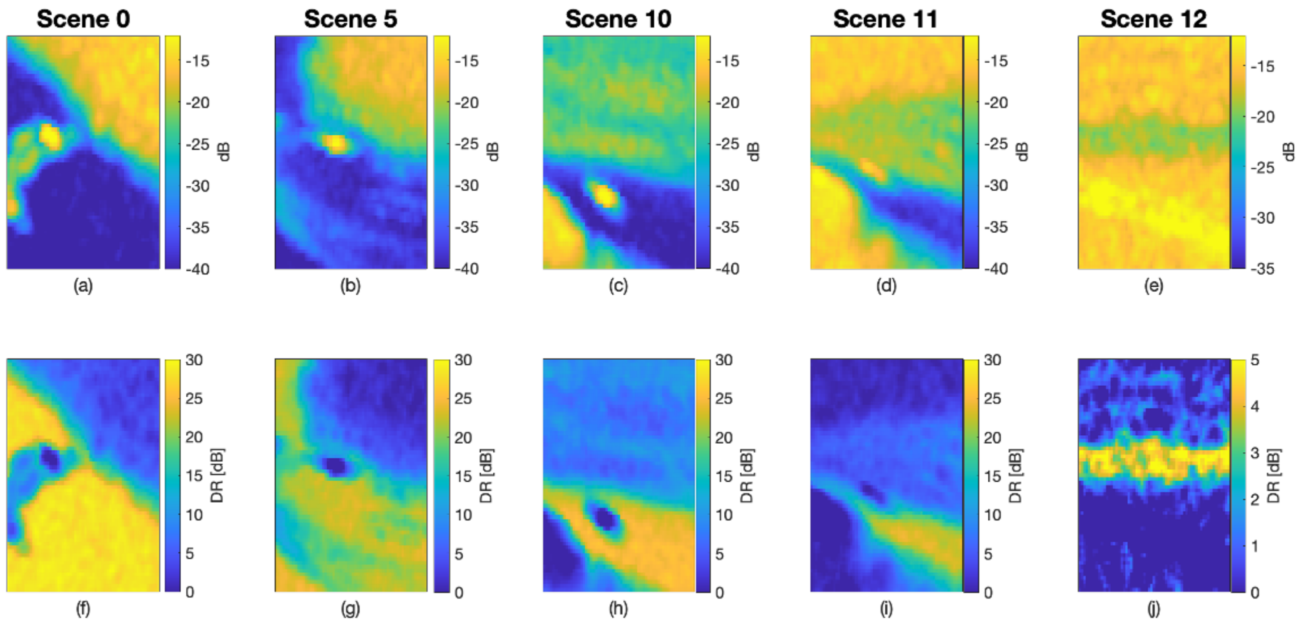


**Fig. 2. (a) – (e) VV polarization image for each of the study regions considered. (f) – (j) DR imagery.**

**Table 1: Water fractions measured at each study site.**

| SCENE # | TIME OF UAVSAR ACQUISITION [UTC] | TIME OF OIL SAMPLE COLLECTION [UTC] | INCIDENCE ANGLE OF STUDY SITE [°] | WIND SPEED [M/S] | WATER FRACTION [%] |
|---|---|---|---|---|---|
| 0 | 16:40 | 16:37 | 30 | 6-7 | 0, 0, 20, 33 |
| 5 | 18:03 | 18:02 | 40 | 6 | 0, 22, 25 |
| 10 | 19:24 | 19:30 | 37 | 6 | 24, 43, 34, 34, 40 |
| 11 | 19:40 | 19:44 | 36 | 6 | 20, 4 |
| 12 | 19:57 | 20:02 | 36 | 6 | 13, 21, 13, 9, 14 |

challenging to determine a water fraction value due to frothing of the oil sample, which hindered accurate readings.

## 3. ANALYSIS

For comparison between the SAR data and the measured oil:water ratios, regions of interest (ROIs) were extracted from the five UAVSAR acquisitions that were closest in time to the sampling. These ROIs, with dimensions of 60 x 60 pixels, were centered on the GPS coordinates of the sampling sites. Table 1 provides information on the specific acquisition times of the UAVSAR data sets considered as well as the corresponding oil sample collection times. Fig. 2 (a)-(e) shows the UAVSAR VV-polarization images for the five sites. Fig. 2 (f)-(j) shows the corresponding DR imagery, which is discussed in the next section.

To obtain volumetric estimates for water content in an oil slick using the co-polarimetric ratio, which is subsequently input into a theoretical backscattering model (refer to [5] and [6] for detailed information on the model), it is crucial to have data with a high signal-to-noise ratio (SNR) data. A straightforward noise analysis was conducted on the regions of interest (ROIs) depicted in Fig. 2 (a)-(e). This analysis involved comparing the pixels in both the VV and HH polarimetric channels with the instrument's Noise Equivalent Sigma Zero (NESZ). Only pixels that exhibited a signal level at least 10 dB higher than the noise floor in both the VV and HH channels were taken into consideration. It was found that only Scene 12 had oil pixels with a high SNR in both VV and HH channels. As a result, only the water volume values relating to scene 12 are discussed in the next section.

## 4. RESULTS AND CONCLUSIONS

In-situ water fraction values corresponding to scenes 0, 5, 10, and 11 showed values of 20% or higher, as indicated in Table 1. However, the in-situ water fraction values for scene 12 predominantly exhibited water fraction values below 20%. Interestingly, the DR imagery reflects the results of the

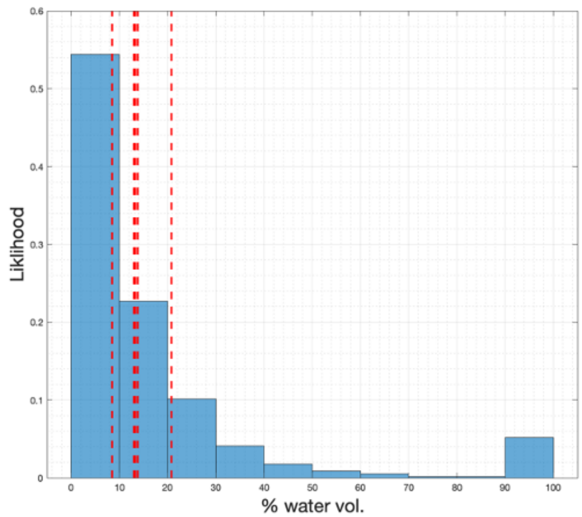


**Fig. 3 Normalized histogram illustrating the distribution of water volume percentages for scene 12, derived from SAR data using the co-polarimetric ratio and the backscatter model. The red vertical lines represent the corresponding values obtained from in-situ measurements.**

noise analysis. DR values for scenes 0, 5, 10, and 11 were determined to have a low SNR and exhibited higher DR values compared to the DR values for scene 12, as depicted in Figure 2 (j). It should be noted that laboratory experiments have shown a correlation between increasing water volume fraction and higher viscosity in mineral oil [8]. This suggests that as the viscosity of the mineral oil emulsion increases due to a higher water fraction, the damping effect on the ocean surface may intensify, leading to a reduction in the returned sensor signal.

In Figure 3, a normalized histogram illustrates the distribution of water volume values obtained from the UAVSAR ROI in Scene 12 (Fig. 2 (e)) specifically for the oil slick regions. The red vertical lines indicate the corresponding in-situ measurements, which are also provided in Table 1. It can be observed that most in-situ measurements are higher than the values retrieved from the backscattering model. This difference could potentially be attributed to sampling bias, as regions with visually darker and thicker oil appearances were manually selected and samples collected preferentially from them, leading to samples that might not fully represent the entire study area imaged by SAR.

Future studies should focus on replicating this experiment using SAR sensors with improved noise characteristics, enabling the estimation of volumetric water content using both the co- and cross-polarimetric channels. Additionally, a larger number of representative samples are required to draw definitive conclusions. Thus, future sampling efforts should include an assortment of in-situ data obtained along cross-sections of the studied oil seepages, ensuring the sampling of oil of various thicknesses.

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