DETECTING MICROPLASTICS POLLUTION IN WORLD OCEANS USING SAR REMOTE SENSING

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ABSTRACT

Plastic pollution in world oceans is estimated to have reached 270.000 tones, or 5.25 trillion pieces. This plastic is now ubiquitous, however due to ocean circulation patterns, it accumulates in the ocean gyres, creating “garbage patches”. This plastic debris is colonized by microorganisms which can create unique surfactants and bio-film ecosystems. Microbial colonization is the first step towards disintegration and degradation of plastic materials: a process that releases metabolic by-products from energy synthesis. These by-products include the release of short-chain and more complex carbon molecules in the form of surfactants, which we hypothesize will affect the fluid dynamic properties of waves (change in viscosity and surface tension) and make them detectable by the SAR sensor.

In this study we used Sentinel-1A and COSMO-SkyMed SAR images in selected sites of the North Pacific and North Atlantic oceans, close to the ocean gyres and away from the coastal interference. Together with SAR processing we conducted contextual image analysis, using ocean geophysical products of the sea surface temperature, surface wind, chlorophyll, wave heights and wave spectrum of the ocean surface. In addition, we started lab experiments under controlled conditions to test the behaviour of microbes colonizing the two most common marine pollutants, polyethylene (PE) and polyethylene terephthalate (PET) microplastics. The analysis of the SAR images had shown that a combination of surface wind speed and Langmuir cells- ocean circulation pattern is the main controlling factor in creating the distinct appearance of the surfactants, sea-slicks and microbial bio-films. The preliminary conclusion of our study is that SAR remote sensing may be able to detect plastic pollution in the open oceans and this method can be extended to other areas.

Index Terms— Microplastics, Surfactants, Sea-slicks, Microbial bio-films, SAR, Sentinel-1A, COSMO-SkyMed, TerraSAR-X

1. INTRODUCTION

Plastic pollution is a global problem because of the harmful effects on marine life caused by ingestion and the potential subsequent bioaccumulation of the pollutants [1]. The total weight of microplastics (in size of <0.33mm-1.00 mm) in the North Pacific is estimated as 21 x 10^8 tons and in the North Atlantic as 10.4 x 10^8 tons [2]. The floating plastic debris will form the new habitat- plastisphere. The microbial bio-films on their surfaces will be different to their surroundings in terms of community structure and will play an important role in degradation of plastic via physical or metabolic means [3]. The other associated processes in the plastisphere will be related with an increase in microbial biomass [4] and triggering subsequent processes- release of the surfactants and formation of the sea-slicks and microbial bio-films [5], accompanied by change in viscosity and the surface tension at the sea-surface microlayer (SML).

The main objective of our research is to identify sites polluted by microplastics using SAR sensors by detecting the surfactants, sea-slicks and bio-films at the ocean surface (the dark patches in grayscale intensity SAR images), otherwise not visible in optical images. The Langmuir cells-ocean circulation pattern is another factor affecting the distinct appearance of the sea-slicks and bio-films. The Langmuir cells are elicit in assisting the accumulation of the surfactants, sea-slicks and natural bio-films at the SML and possibly are modifying the fluid dynamic properties, and suppressing the capillary waves [6]. These suppression effects on a capillary waves are detectable by the SAR sensor and therefore can assist us in identification of the microplastics contamination. The Remote sensing analysis was carried out together with the start of the lab experiments under controlled conditions, with the aim to understand the processes associated with the microbial colonization of the polyethylene (PE) and polyethylene terephthalate (PET) microplastics. The final objective of our research is to develop machine learning algorithm, grounded on SAR data and backscattering effects from the surfactants, sea-slicks and microbial bio-films, assisting in detecting microplastics polluted areas in the open oceans. This piece of the research is could represent a key point in supporting the inventory of microplastics and to expand the scientific knowledge in microplastics research.

2. SURFACTANTS, SEA-SLICKS AND MICROBIAL BIO-FILMS AT THE SEA-SURFACE (SML) LAYER

The degradation and disintegration processes of plastic debris will be followed by release of the surfactants and formation of the sea-slicks and bio-films, in general not visible in optical images, because of transparency of the surfactants and bio-films. The formation of bio-films will be initiated by the attachment of proteins, followed by individual bacteria, and triggering other microbial species to colonize. In the Atlantic Ocean the bio-films are consists from bacteria, fungi, diatoms, protozoans, larvae, and algal spores embedded in an extracellular polymeric substance matrixes [7]. The additional release of the surfactants at the SML will be caused by more soluble organic components from the sea-slicks and bio-films. We can hypothesize, that microbes colonizing microplastics will produce surfactants, visible on radar images as a dark spots. According to our hypothesis, this “ring-like” and linear features which are seen on radar images are possibly due to microbiological colonization of microplastics. The modification of the fluid dynamic properties at the SML, seen as suppression of capillary waves can be described as a mechanism of resonant microwave scattering from the wave spectrum, presented on SAR images as an absence of Bragg scattering [8].

Findings suggested, that no clear relationship is present between surfactant activity at the SML and the total chlorophyll production [9]. However, the high ambient wind in speed of >12 m/s^{-1} is essential in continuous supply of the surfactants and creating the bubble scavenging from the lower water column [10]. The non-ionic soluble surfactants are able to suppress the wave tension forces, reduce the net oceanic CO_2 uptake in 15-50% and to introduce a large dampening effect on the air-sea exchange of N_2O. The highest concentration of plastic is found in the eastern North and South Pacific Oceans located between 25º-41ºN latitude, according to 11 years sampling data (2001 to 2011), thus corresponding to the location of the Great Pacific Garbage Patch [11]. The accumulation mechanism of the Langmuir cells and low wind speed is found to be a main meteorological factor influencing the distinct appearance of the sea-slicks and bio-films [12]. The impact from the Langmuir cells at the SML can be connected to increase in concentration of the surfactants and sea-slicks, and possibly in increase in the surface tension, which can be modelled as a surface force per unit volume, described by the continuum surface force model (CSF) [13].

3. DETECTING MICROPLASTIC POLLUTION USING SAR REMOTE SENSING

The longstanding presence of a plastic debris remaining at the near-surface of the ocean for period of up to 30 months and possibly longer [11], can provide opportunity for repeated SAR acquisitions to monitor the selected sites. SAR images are important, because available plastic concentrations at the SML are not sufficient to change the ocean colour and transparency of the surfactant-associated bacteria and bio-films, hiding the visibility of surfactants, sea-slicks and bio-films on multi-spectral images.

A similar study on detecting natural surfactants in the Gulf of Mexico used large datasets of C-band Radarsat-1 SAR images. They found the optimum wind speed and incidence angle range (from 3.5 to 7.0 ms^{-1} and from 22º to 40°, respectively) to observe those slicks in SAR imagery [14]. The polarimetric SAR technique and image segmentation were successfully applied to detect marine pollution (oil spills and bio-genic films), based on the dependency of subsurface wind and slicks on the sea surface [15]. The separation of polarization difference (PD) and a non-polarization (NN) components using the Bragg scattering model was applied on C-band Radarsat-2 quad-polarized SAR data in VV and HH polarizations to find a high suppression of NN backscatter by surfactants films [8]. The effects from the activity of surfactant-associated bacteria is also difficult to spot during *in-situ* sampling, mentioned in the attempt to synchronize acquisition of Radarsat-2 and TerraSAR-X satellite data and *in-situ* sampling [14].

In our study we used VV-polarized SAR images because of clearer and distinct dark signatures. We also observed low standard deviation of wind values ranging from 0.12 to maximum 4.44 ms^{-1}, measured by Aquarius and CERSAT scatterometer, indicating a matching distribution of these SAR signatures with the selected wind range. Additionally, we considered the ancillary information on ship discharge based on ship traffic to separate plastic contaminated areas from oil spills and other unknown contamination.

4. RESULTS

4.1. The SAR dataset

The North Atlantic test site is covered by Sentinel-1A images, provided by European Space Agency (ESA). The images are Level 1, Extra Wide Swath (EW) Ground Range Detected (GRD), in full resolution 25 by 25 meters. The dataset includes latest acquisition from Sentinel-1A, dated 03 November 2017. The North Pacific area is imaged by COSMO-SkyMed, StripMap HIMAGE, Level 1B (DGM), full resolution after resampling 4 by 20 meters.

Figure 1 shows VV-polarized SAR image acquired by Sentinel-1A in the North Atlantic. In this figure we can observe dark areas whose shape is sometimes patched and sometimes are linear. Similar stripes and "ring-like" signatures can be observed in the middle of the Pacific Ocean (no active shipping) in the COSMO-SkyMed image (Figure 2). The areas with the dark signatures falls in microplastics polluted areas, shown in Figure 3- in "solutions of microplastics count", and presenting high concentrations of microplastics over the North Atlantic and North Pacific oceans [16].

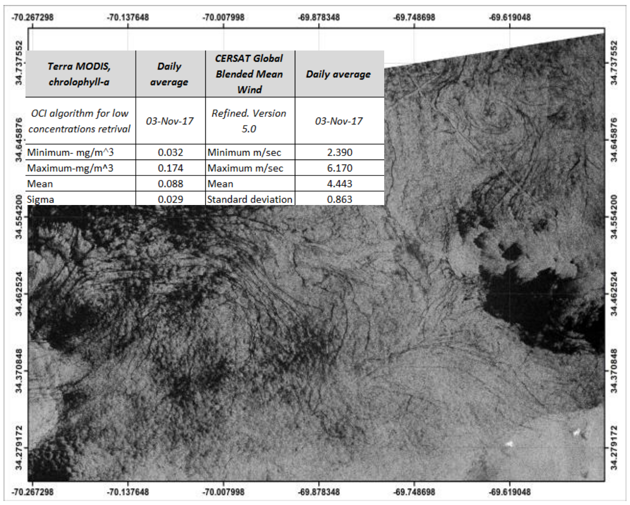

Figure 1- Sentinel-1A SAR with presumed surfactants and sea-slicks. Date of acquisition-03/11/17, 22:00 pm.

Comparing both images, it appears that low wind (0.12 to 4.44 ms^{-1}) may have enhancing effect on visibility of the black patches, which are not wind features, making us to hypothesize that they are related to the surfactants. However, in high wind areas (from 6 ms^{-1}) we can observe strikes that are generally associated with the oil spills.

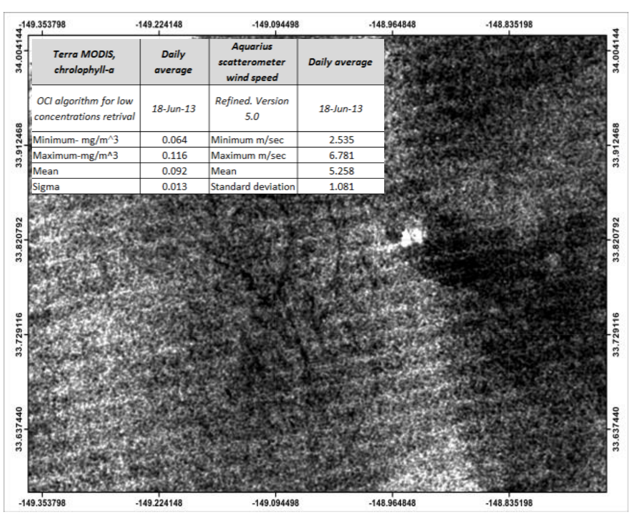

Figure 2- COSMO-SkyMed SAR image with presumed surfactants and sea-slicks. Date of acquisition-18/06/13, 15:45 pm.

We can also hypothesize, that these "ring-like" and linear structures in the Atlantic Ocean are occur because of the microbial colonization of microplastics related with low shipping activities and low chlorophyll-a concentrations.

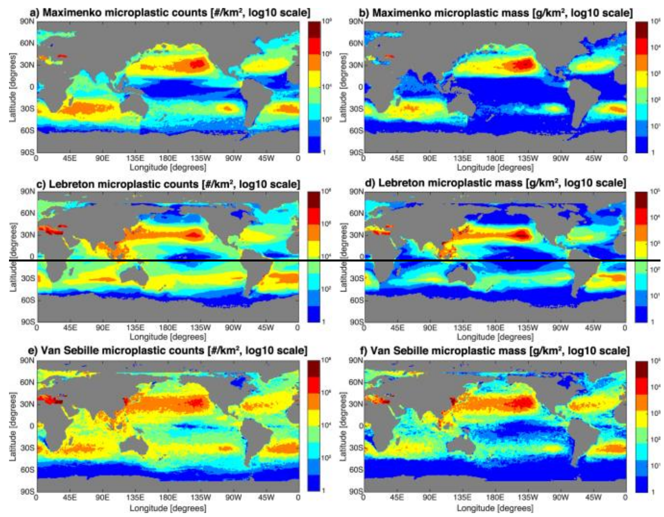

Figure 3- Solutions of microplastics count [16].

4.2. The future experiments

In addition, to the radar image processing, we will carry experiments in the lab, using controlled conditions. The aim of this work is to research the two most common marine pollutants polyethylene (PE) and polyethylene terephthalate (PET) microplastics, by observing the effect of microbial colonization and release of the surfactants. We are going to test the selected microplastics in two separate sets of aquariums and to verify the obtained results using two controls without microplastics. To initiate the surfactants growth, the 30% of the actual seawater as a microbial inoculum will be added to the experimental set. The microbial inoculum will be sampled in remote location somewhere in the UK coast, in locations where is possible to exclude any known and unknown contamination. The aim of this work is to explore the relationship between surfactant concentration, wave amplitude and change in the viscosity and surface tension triggered by microbial colonization of the microplastics.

4.3. The future acquisitions

The results presented in this paper will be further expanded by adding the new acquisition from COSMO-SkyMed satellite and TerraSAR-X from German Aerospace Center. It is expected, that by expanding the current dataset and using different sensors and image formats will assist us in more clearer identification of the surfactants, sea-slicks and films, otherwise not entirely visible in Sentinel-1A and COSMO-SkyMed StripMap images. Such an extra addition of COSMO-SkyMed ScanSAR WIDE and TerraSAR-X images will also enhance the area coverage and temporal resolution.

5. CONCLUSION

From preliminary results we can conclude, that VV-polarized SAR images are showing the distinct dark signatures, which can be presumably linked to the microbiological activity related to colonization of microplastics. These signatures are shown dependency on a certain range of winds, starting from 0.12 to maximum of 4.44 ms^{-1}. No significance with presence and or absence of the chlorophyll-a are found. The research is still on-going, with the final aim to develop the machine learning algorithm, on identification of surfactants, sea-slicks and bio-films, grounded on SAR data and backscattering effects from the surfactants, sea-slicks and bio-films. The machine learning algorithm will be aided by textual image analysis, modelling of the surfactants accumulation mechanism based on oceanographic processes (Langmuir cells) and knowledge about microplastics and surfactants behaviour from the lab experiments. The results will be verified against *in-situ* data (Figure 3) and theoretical concepts of plastic and microplastics from the scientific studies. We can also conclude, that possible sources of false alarms on a SAR images are possibly due to low wind (small waves with almost negligible roughness) and other oceanographic features, apart from Langmuir cells and Bragg scattering.

6. ACKNOWLEDGEMENT

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