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Detecting floating plastics using a high-frequency X-band radar

A feasibility study on unconventional monitoring techniques for the detection of plastics

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Summary

Ship-based X-band radar was tested for the detection of floating plastics. Plastic items are likely to a have a different radar reflection than items of other materials with the same size above the water, since they have different dielectric constants. This principle may be used in the future to distinguish a floating plastic item from other items. In this feasibility study we carried out three measurement campaigns in the Rhine-Meuse delta on the 4th and 6th March 2020 and on 16th March 2021. In the first measurement campaign, it was found that large containers could be detected up to longer distances, when using a vertical transmit and vertical receive polarization instead of a commonly used horizontal transmission horizontal receive polarization. The second and third measurement campaign items were spaced 10m apart on a rope, aiming to test the maximum distance at which an item could be detected. The largest items (jerrycans of 2, 5 and 19 l) were detected at 150 m, and sometimes up to 500 m. A bubble wrap with four wooden buoys was probably detected at 100 m. Cylinder sized items (1.5 l empty PET bottle and a metal cylinder) were detected intermittently, which seemed to relate to waves generated by a passing commercial vessel. A 0.5 l empty PET bottle was not detected. Still, this feasibility study indicates that X-band radar presents a potentially unique monitoring method for detecting and tracking larger plastic items, due to its ability to continuously monitor through the day or night at high temporal resolution.

Contents

1 Plastic leakages in the aquatic environment

1.1 Introduction

Increasing recognition of rivers as major contributors of plastics in the ocean (Lebreton, et al., 2017) has led to a shift in policy for the quantification and monitoring of litter at their source (González, et al., 2016). Deltares has been involved in several research projects concerning the theme of plastics, aiming to estimate the transport of macroplastics in rivers or to determine locations where the concentration of macroplastic items is larger. At those particular locations in rivers, devices to remove macroplastics can be installed efficiently. In all these projects it was concluded that observations of macroplastics were too limited to draw conclusions and to validate model results. The observations only give snapshots of floating macroplastic transport in rivers, such as by visual counting from a bridge (van Emmerik, et al., 2019). In the framework of the Riverine and Marine floating macro litter Monitoring and Modelling of Environmental Loading (RIMMEL) project, cameras were installed in the period 2015-2017 on bridges where macroplastic items larger than 2.5 cm were also counted. An example of a study that applies machine learning to detect aquatic plastics is Wolf et al. (2020), who are using aerial photographs to detect plastic litter larger than 2.5 cm. We are not aware of a publication that shows results of automatic plastic item detection from standard cameras installed on bridges, which have the potential to estimate the number of passing plastics continuously. To understand the behaviour of floating macroplastics, monitoring data is needed, and preferably continuously to understand how the behaviour changes with conditions.

1.2 Monitoring techniques

The recent focus on the issue of plastics requires innovative and unconventional thinking in the way we monitor them, as the development of monitoring methodologies and techniques are rather new. Therefore, alternative sources of data can provide an untapped potential into the monitoring of plastic flow in such water systems, including the use of instruments not originally designed for such applications. Remote sensing (RS) offers a potentially complementary technique in the detection of plastics. RS refers to the collection of data of a particular location without direct contact and includes both the use of Earth Observation (EO) instruments (e.g. satellites and Unmanned Aerial Vehicles), and the use of in-situ instruments such as field-spectrometers, and sonar instruments for bathymetry. Such a technique could be used to collect useful data that would complement modelling results and shed insight into the behaviour of plastic flows in rivers.

Open-source satellite datasets such as the Landsat or Sentinel constellation include optical, infrared and radar sensors. However, such satellites only offer a maximum spatial resolution of 10m, and because neighbouring pixels can also affect the signal of another, the lack in spatial resolution restricts the ability to observe and understand the transport and flow of individual items plastics in rivers. Optical satellite remote sensing is only effective at detecting large conglomerations of floating waste. Lastly, aerosols, clouds and precipitation render many optical and infrared sensors little to no use during poor weather conditions: infrequent satellite observations are not suitable for highly dynamic targets in dynamic environments such as a river system.

Contrary to optical/near-infrared sensors, radar (Radio Detection and Ranging) remote sensing is classified as an ‘active’ technique as microwaves are sent out and the reflected signal is measured by the instrument. The advantage of radar is that it can be used despite adverse weather conditions as the signal can pass through clouds and rain. By measuring the time taken between pulses emitted and received, information about roughness, size, density and dielectric properties of the material can be derived from such signals. Although EO may not always be suitable for monitoring the behaviour of plastics due to the low spatial and temporal resolution, in-situ radar instruments are widely available and able to monitor continuously, even during the night. Despite radar remote sensing being typically used in the field of meteorology and ocean physics, it presents itself as a promising technique for the detection of floating plastics in aquatic environments, due to the main reason that water and plastic both have different dielectric constant and surface roughness properties, allowing for differentiation between both material types at any given surface in time (Hafeez, et al., 2019).

1.3 Research question and hypothesis

An instrument that would be suitable for such an implementation would be an X-band radar instrument. High frequency radar instruments produce high resolution images due to the short wavelengths they have, and have been typically used as marine navigational systems, with a high temporal frequency of detection to prevent collision. Given its applications in object detection, the hypothesis is that radar remote sensing can offer itself as a potential tool for detection of floating plastics in rivers to better understand the behaviour of the floating plastic flow in water systems. Furthermore, as different materials have different dielectric constants, there may be potential to differentiate plastic from other organic matter floating in the water e.g. tree branches. The applicability, however, is expected to work with larger size fractions of macro-plastics, though the size limit for detection remains unknown. As a rule of thumb, we assume that If the wavelength is much longer than the size of the target, the target may not be visible because of poor reflection.

A feasibility study was carried out into the applicability of using radar remote sensing as a complementary monitoring tool. The research questions to answer are as follows, in order of priority:

1. Can X-band radar detect floating plastic items, and if so, from what size are they able to?
2. Can X-band radar be used to track movement of floating plastic items, thus monitoring the behaviour of plastic transport?
3. Can floating plastic items be distinguished from other material types?
4. What is the effect of variations in weather and flow conditions during the survey on the above research questions?

2 Methodology

2.1 Measurement campaign set-up

The research was conducted in collaboration with Sens2Sea, a Dutch small-medium enterprise (SME) specializing in radar instrument development and applications in the coastal and marine setting. The radar instrument used in this research project has an antenna of 12 feet (~3.66m) and was mounted on a cherry picker. This provided the possibility to adjust the pole height of up to 12m high. A higher position of the sensor improves transmission and receiving angles and allows for better and higher spatial resolution, also because of reduction in interference at such a height from other objects such as groynes, buildings or jetties, however, unfavorable weather conditions do not always allow the radar instrument to be hoisted at the maximum height. The radar instrument has two transmission and two receiving possibilities: vertical transmission and vertical receive polarization (VV) and horizontal transmission and horizontal receive polarization (HH). Both polarizations were tested in the first campaign.

Figure 2-1: Photograph of the MRD Hunter. Credit: Sens2Sea

Figure 2-2: Radar instrument mounted on the center of the MRD Hunter

For this project, three measurement campaigns were carried out under varying weather conditions on the 4th and 6th of March 2020, and 16th of March 2021. The radar instrument was mounted on the center of a vessel, *MRD Hunter*, approximately 1m above the surface of the water. The MRD Hunter is 27m long with a 7m width, and is pictured in Figure 2-1. The flexibility in adjusting the buoyancy of the vessel meant an increase in accessibility to shallow areas, allowing easy retrieval of plastic items. All three days had windy conditions. The 4th of March was characterized by clear skies while the 6th March had overcast conditions, and the 16th of March had overcast conditions and light rain occurred. The radar on the cherry picker was raised to a height of approximately 10m and 11m on the 4th and 6th of March respectively, and the set-up is shown in Figure 2-2. The 16th of March a different radar was used, which only has the VV option. Its resolution is the same as for the X-band radar used in the first two campaigns.

To test the detection capabilities of the radar instrument, ropes with different plastic items tied to it were released from the boat, and retrieved afterwards. For the 4th March, a white nylon rope was used, with various plastic items attached to it spaced 3m apart. The plastic items used are shown in Figure 2-3. Although the white jerry cans were an artificial representation of reality, the rightmost 3 items (container, bottle, bubble wrap) were some of the typical debris that could be found in the aquatic environment.

Figure 2-3: Types of plastic items attached to the rope that was deployed on 4 March 2020. To ensure sufficient buoyancy of some of the materials, makeshift buoys were attached to them made of low-density wood. All items used in these measurement campaigns were successfully retrieved.

The real-time results of the first measurement campaign informed the set-up of the second measurement campaign. For the 6 March 2020, a new rope set-up was introduced. As the rope from the first measurement campaign was found to be too thick and dense, lighter and thinner ropes were used instead, both also made from nylon. The second campaign was also focused on detecting individual items, therefore, the plastic items attached to the ropes were spaced approximately 10m apart. Two ropes of 6 items in total were deployed, with smaller plastic items used instead such as a 500ml PET bottle and plastic shopping bag.

During the third campaign, we evaluated the detection success of each item by comparing radar images with photos taken from the boat. We carried out 3 series of observations, using the same blue and green rope again with every 10 m an item. The focus in this third campaign was on testing smaller items (more commonly found in rivers), and testing the influence of the material type (dielectric constant) on the detection success. Besides plastic items, we also used wooden and metal items of similar shape (roughness) as some of the plastic items.

2.2 Radar instrument and data processing

For the three measurement campaigns, the radar instrument used was an X-band pulse radar, with a short pulse of 50 nanoseconds and a resolution of 7.5m in the transmission direction, or the line-of-sight from the installation of the radar. The azimuthal resolution is approximately 0.65°, meaning that at 100 m away from the radar the resolution in azimuthal direction is 1.1 m, and at 660 m away it is equal to the resolution in transmission direction (7.5 m). An illustration is shown below to highlight the resolution of the radar signal.

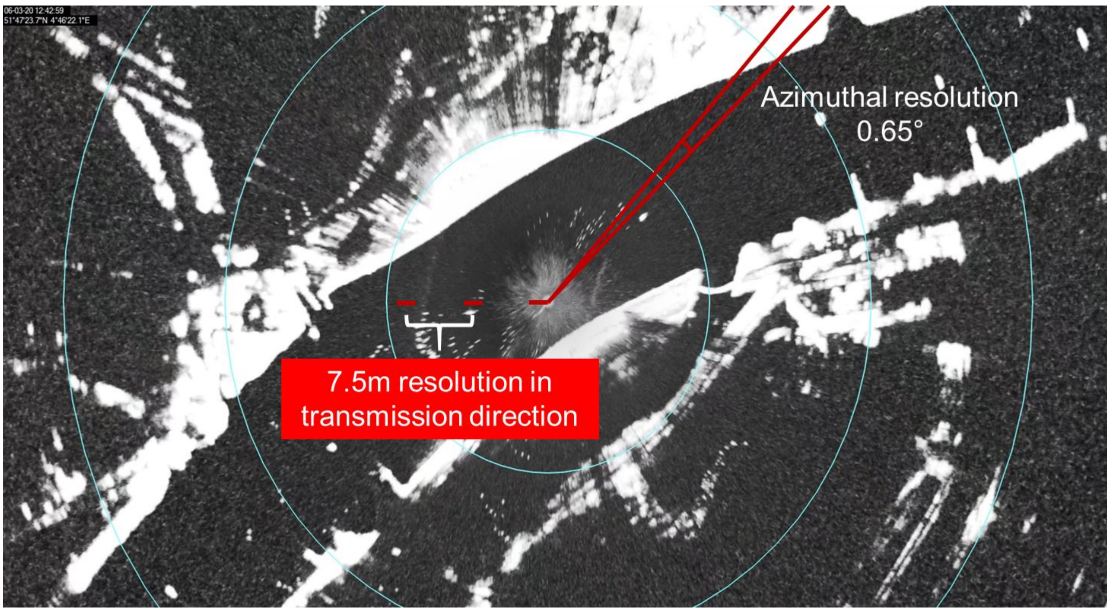

Figure 2-4: Example image with illustration of the resolution for both the azimuthal and transmission direction. The angle and distance portrayed are exaggerated. Image credit: Sens2Sea

The data were collected and analyzed in real-time using Sens2Sea's radar software. Continuous recording allows the data to be re-analyzed or re-processed at a later stage. The dynamic radar signal collected is continuously calibrated against the signal of water, and later on, adjusted to an absolute value of relative brightness. Brighter pixels, therefore, indicate a stronger signal being reflected back.

Post-processing procedures included image contrast adjustments, with the final output in a form of a video. The filtering applied for 6 March was heavier than 4 March due to the presence of low clouds on the 6 March, which introduces more speckle in the signal as water vapour interferes with radar signals. This would explain the slight contrast differences in the results of 4 and 6 March. The characteristic of the antenna is based on IMO[1] regulations to avoid loss of navigation information if a ship navigates in heavy seas so the opening angle is 10 degrees up and 10 degrees down (Figure 2-5). A vertically polarized antenna is, therefore, more sensitive to water droplets and clouds. Low clouds are in the beam of the antenna and are visible so the filters must be adjusted to suppress noise in the signal.

[1] IMO refers to the International Maritime Organisation responsible for global maritime-related affairs.

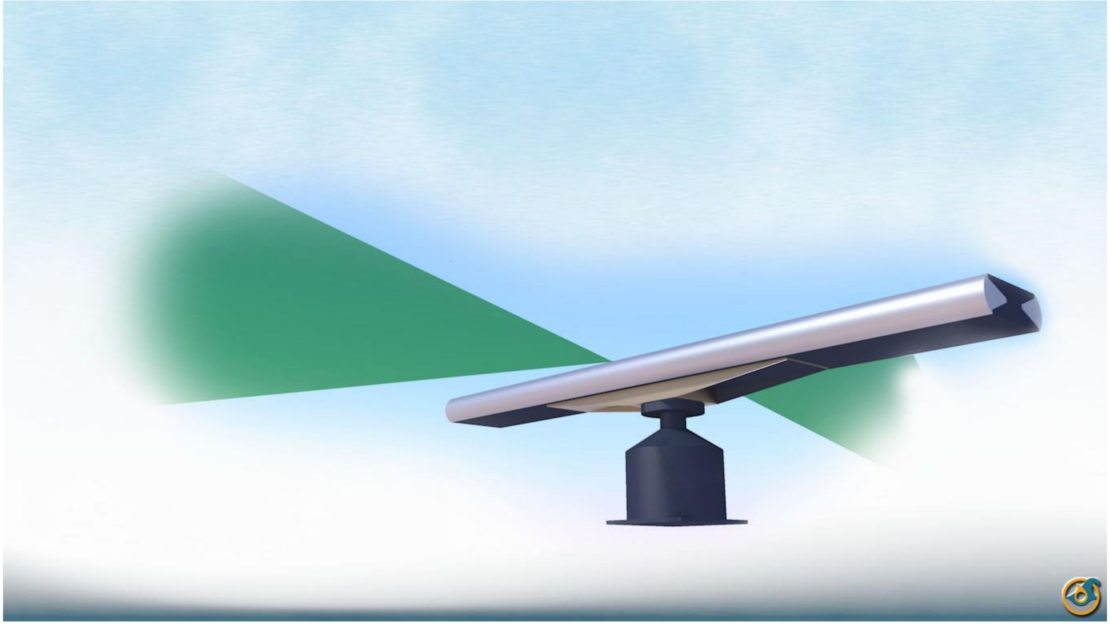

Figure 2-5: Image of an antenna with the field-of-view (green) based on a 10° opening angle, up and down. Image courtesy of Sens2Sea.

3 Results and Discussion

3.1 Wind and hydrodynamic conditions

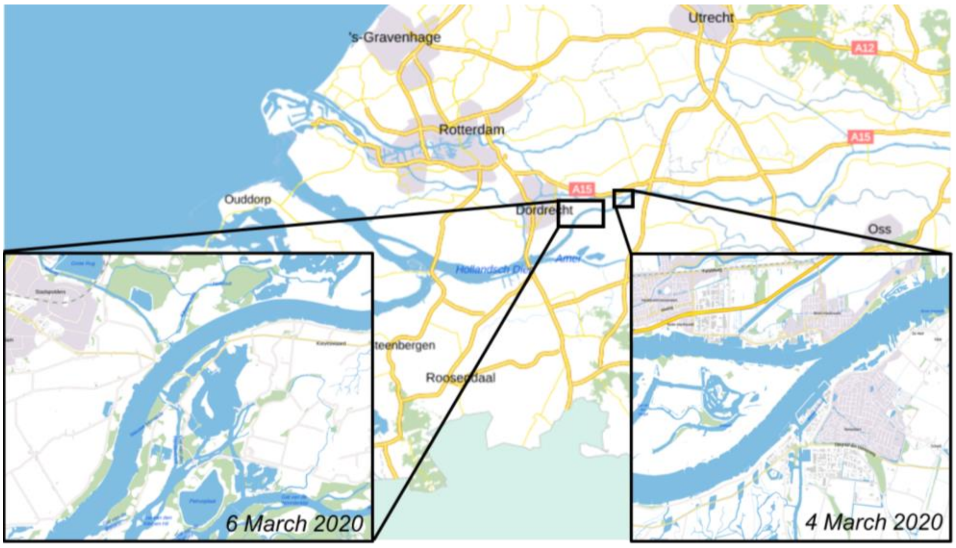

Figure 3-1: Open Street Map view of both locations for the respective measurement dates. The campaigns were mainly carried out close to the city of Dordrecht and only along the Rhine.

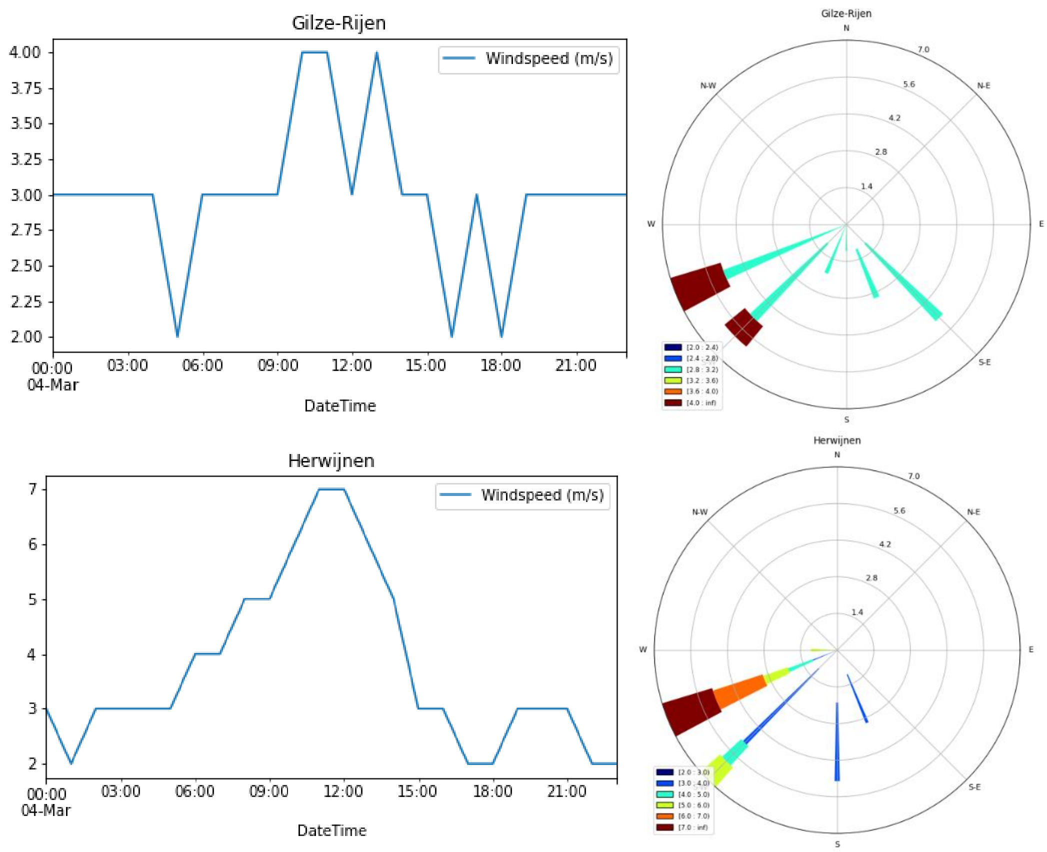

Figure 3-2: Wind speed (m/s) and windrose plots of the weather station Gilze-Rijnen (top) and Herwijnen (bottom) for 4th March 2020

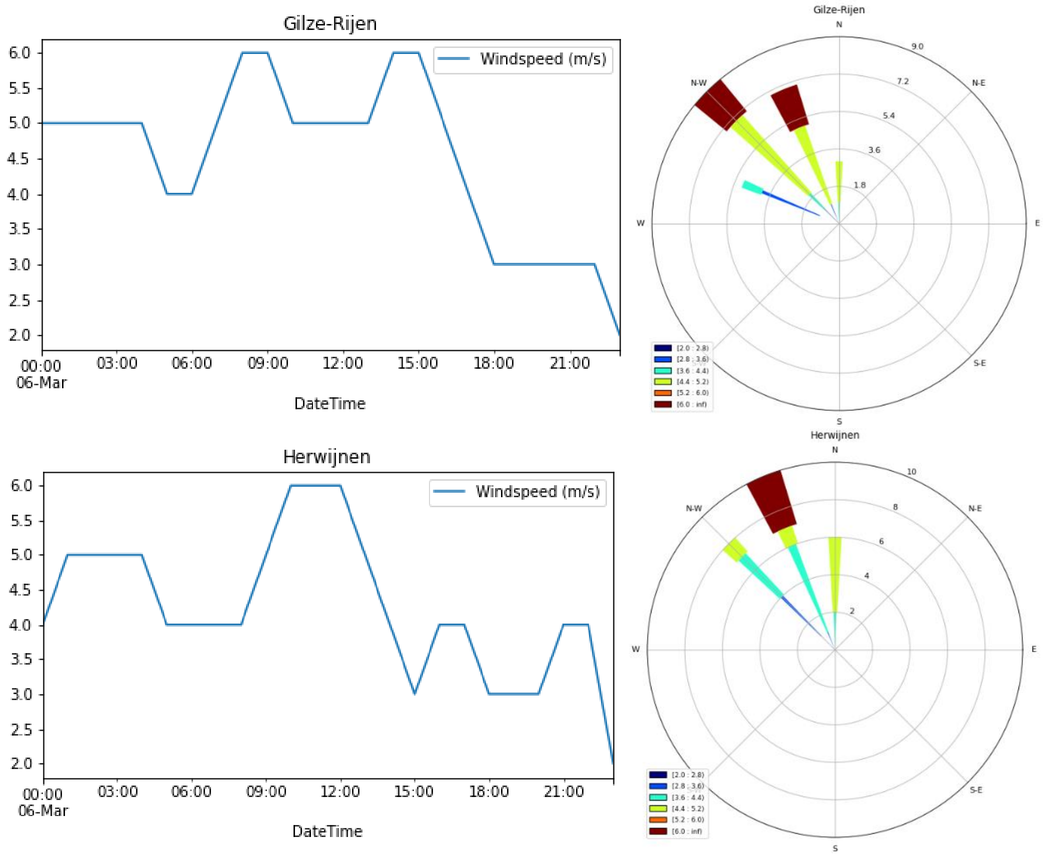

Figure 3-3:Wind speed (m/s) and windrose plots of the weather station Gilze-Rijnen (top) and Herwijnen (bottom) for 6th March 2020

The locations of the measurement campaign for the 4 and 6 March 2020 are indicated in Figure 3-1, which were carried out close to the city of Dordrecht and in the Rhine. The specific locations were chosen primarily for their low traffic volume, so as to not interfere with regular waterway traffic.

On the 4 March 2020 during the measurement campaign between 12:00-15:00 UTC+1, windspeeds recorded at two nearby stations, Gilze-Rijnen and Herwijnen, were between 3-4 m/s and 3-7 m/s respectively. The wind direction was dominated from a south-west and west-southwest direction at both stations (Figure 3-2). Furthermore, the Gilze-Rijnen station is at an altitude of 14.9m, while the Herwijnen station is at 0.7m. On the 6 March 2020, windspeeds were recorded at 5 and 6 m/s on average during the measurement period (1200-1300), with a dominant wind direction of north-west and north-northwest (see Figure 3-3).

On the 16th of March the wind was moderate with a dominant north-west direction. The flow direction was westwards during the three series, corresponding to ebb tide.

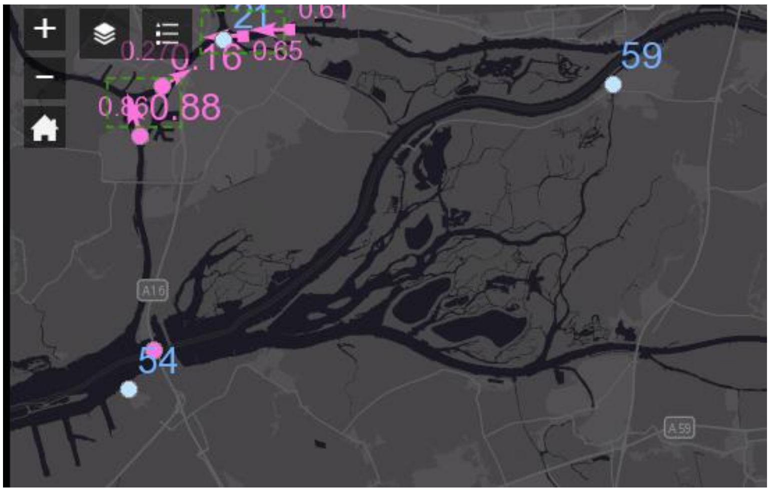

Figure 3-4: Map of the Biesbosch area which indicates the locations of the water level stations: Werkendam Buiten is marked by '59' in the upper right corner towards the northeast direction.. Moerdijk is marked by '54' at the lower left towards the southwest direction.

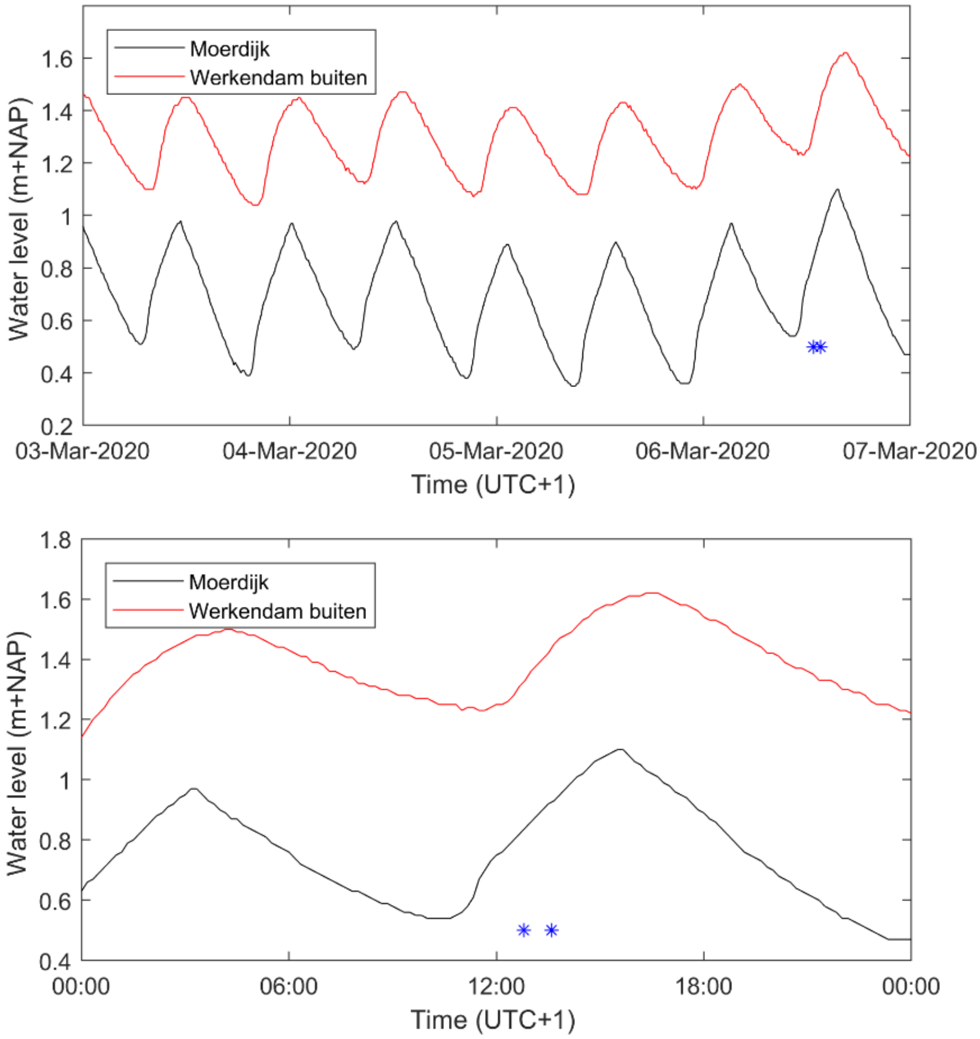

Figure 3-5: Water levels at the two monitoring locations, Moerdijk and Werkendam Buiten, for the period in which radar observations were carried out. (Top) Water levels of the two locations for the period 3 March to 7 March 2020. (Bottom) Water levels for the 6 March 2020 (Table 3.2).

Water levels at Moerdijk (seawards of the plastic detection location) and Werkendam buiten (landwards) show that the water level was lower at Moerdijk at all times (Figure 3-4, Figure 3-5). The cross section averaged flow was always directed seawards. The river discharge at Lobith was around 5000 m^3/s, which is 2.5 times higher than the long-term average. Port of Rotterdam observes 10-minute average flows at Moerdijk, but historical records not available on website.)

3.2 First measurement campaign - 4th March 2020

Table 3.1: Measurement metadata from 4-3-2020. GPS coordinates were also registered in the radar data.

Time (+1 UTC)	Transmission V = Vertical H = Horizontal	Distance (metres)	Boat position	Plastic position	Remarks
14:15	V	315	51.812, 4.873	51.812, 4.874	-
14:26	H	315	51.81, 4.871	51.812, 4.874	-
14:34	H	534	51.808,4.868	51.812, 4.874	-
14:40	V	570	51.808, 4.868	51.811, 4.874	-
14:52	V	1514	51.805, 4.863	51.811, 4.874	Presence of birds
15:01	V	2130	51.803, 4.8576	51.811,4.874	No plastic signal, parts of river bank disappeared on-screen, last seen plastic position registered as location

Weather conditions on 4 March 2020 were observed to be mostly clear with some mid-level clouds when both transmission directions were tested during the measurement campaign. During the measurement period, plastics could be detected as a markedly brighter signal, corresponding to higher backscatter. Plastics were found to be detectable in both transmission directions (VV and HH). The presence of buoys in the channels where the measurements were carried out expressed a bright, distinct signal in the images, allowing their position to be used as reference for location of the plastics in the channel in case of strong currents or drifts. An example of the bright buoy signal is shown here in Figure 3-6 below, marked by the 3 red rectangles. As part of the postprocessing, a circular light blue marker is placed every 500m to provide a reference to the actual distance.

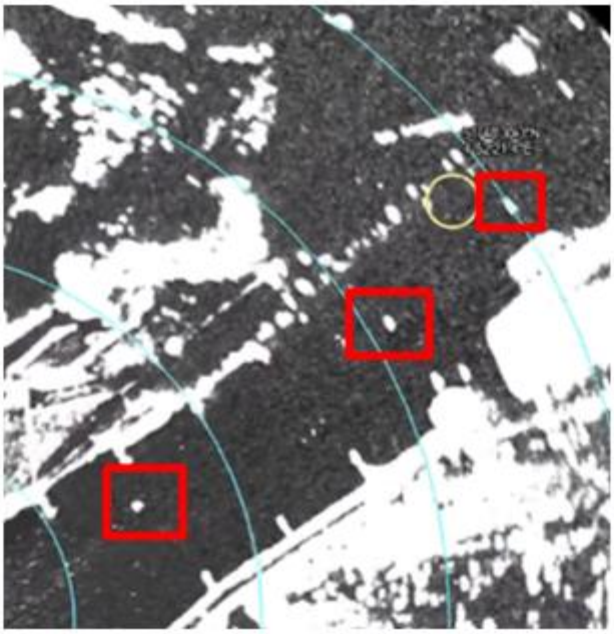

Figure 3-6: X-band radar image showing examples of the bright signal expressed by buoys in the channel, that could be used as a reference point

When the plastics were first deployed at around 14:15, the radar was transmitting in the vertical direction. Immediately after deployment, a thin bright line is observed in the radar images, as shown in Figure 3-7. During deployment, the plastic rope configuration was released along the rope, instead of a bundle. In the azimuthal view, it therefore expresses itself as a long, thin line in the immediate vicinity of the radar. Individual items were not detected in the radar images from 4th March, which can be explained by the method of deployment and the transmission resolution of 7m, which is bigger than the spacing of 3m between the individual plastic items.

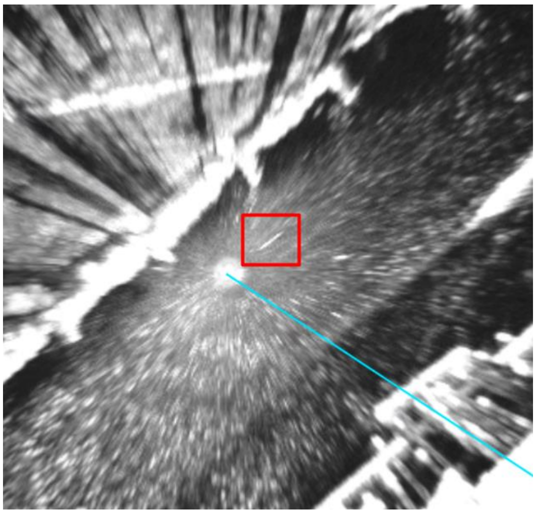

Figure 3-7: Radar image taken in the vertical transmission at around 14:15. The area immediately around the boat shows high amount of speckle. The straight blue line represents the heading of the radar instrument, pointed from the bow of the boat.

Furthermore, the area immediately surrounding the boat appears highly granulated, decreasing in granularity further away from the boat. Figure 3-8 also shows the granulated areas immediately around the boat but decreases sharply after the first 500m mark. Although part of the postprocessing involves calibrating the brightness values such that the relevant signals can still be detected, it is not possible to completely remove or solve the issue of speckle within these images. Strong, windy conditions can also generate smaller waves, including capillary waves, with wave facets oriented towards the signal which have a more scattering effect and can contribute to more reflections of the radar signal closer to the instrument.

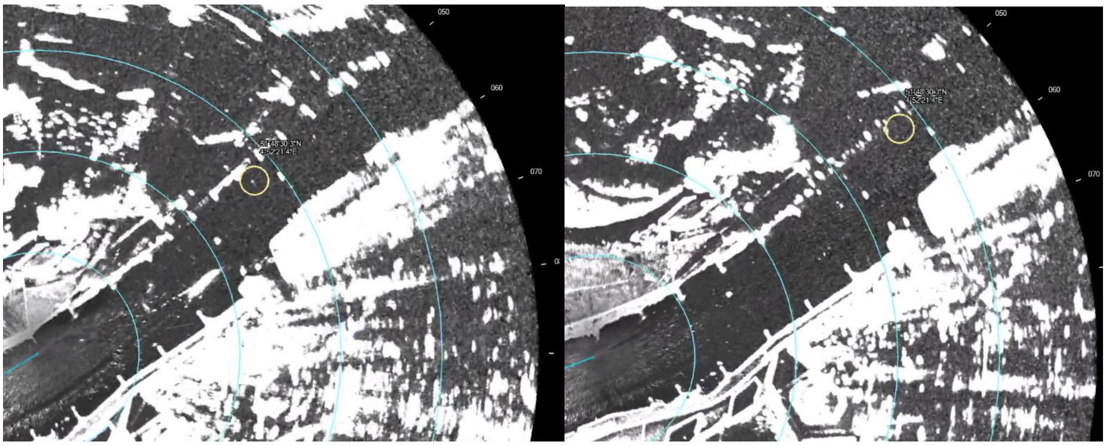

Figure 3-8: Plastics detected at 14:58 (left) and disappeared at 15:01 (right), approximately 1.5km away from the boat. Plastics are manually marked by the yellow circle in each frame.

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For the vertical transmission (VV, Vertical transmit, Vertical receive), plastics were detected from up to 1.5km away from the boat. Immediately following deployment of the plastic rope configuration, the location of the plastics was tracked in real-time with the X-band radar and visually corroborated. A marker was placed around the signal of the plastics detected and tracked throughout the measurement campaign until the signal disappeared. As seen in Figure 3-8, the plastics presented itself as a bright point from the moment of deployment up until approximately 14:59, nearing 1.5km away from the boat. Around the time where the signal of the plastic configuration disappeared, the boat had also reached a bend of the river such that the groynes along the river started to intersect with the transmission line from the boat to the plastics. Although the plastic signal had weakened considerably around the 1.5km distance, it is not possible to conclude if this is the detection limit of the X-band radar instrument or if the groyne had interfered with the signal.

For the HH polarization plastic was only detectable up to approximately 530m. Therefore, only the VV transmission was used in the remainder. For the radar instrument used in this measurement campaign, the sensitivity of the vertically polarized antenna can be up to 3dB better than the horizontally polarized antenna. This could also explain why objects are better detected in this polarization direction.

3.3 Second campaign - 6th March 2020

For the 6th March 2020, a different rope configuration was used. Three different plastic items were attached to a nylon rope spaced 10m apart. Details of the plastic items tied to the ropes can be found in Table 3.2. During deployment, the ropes were found to bundle more closely to each other, reducing the spacing between the plastic items. It was not possible to establish or monitor the spacing between the ropes throughout the measurement campaign. Additionally, following on the preliminary results of the different transmission directions tested from the 4th March 2020, only the vertical transmission direction was tested. Plastic items were visible up to approximately 1.1km away from the position of the boat, however, the strong drift of the plastic items behind groynes or onto the river bank prevented testing of detection further than 1.1km. Table 3.3 provides details of the measurement, including first observations of the signals observed from the plastics. Yet, despite the issue of bundling, individual plastic items could be detected as well during this measurement campaign.

Table 3.2: Item descriptions of each rope configuration (dubbed 'Blue' and 'Green'). The item numbering is done in the same order as the actual rope configuration

Rope	Item number	Item name	Length (m)	Height above water while floating (m)
	1	19L HDPE jerry can	0.43	0.27
Blue	2	Plastic bubble wrap with four mini wooden buoys	1.34	<0.03
	3	1.5L PET bottle	0.34	0.08
	4	19L HDPE jerry can	0.43	0.27
Green	5	Plastic shopping bag	0.38	<0.03
	6	5 l jerrycan	0.31	0.13

Figure 3-9: Pictures of the plastic items on the blue (item 1, 2 and 3) and green (item 4, 5 and 6) ropes.

Table 3.3: Measurement metadata from 6-3-2020. GPS coordinates were also registered in the radar data. The plastics were first deployed at 12:48

Time (+1 UTC)	Transmission V = Vertical H = Horizontal	Distance (metres)	Boat position	Plastic position	Remarks
12:48	V	0	-	-	Time of deployment, GPS coordinates were not recorded
12:54	V	100	51.792, 4.773	51.791, 4.772	5 distinct signals observed
13:00	V	170	51.791, 4.769	51.789, 4.769	4-5 signals observed
13:04	V	270	51.790, 4.765	51.788, 4.768	4 signals observed but ropes were 40m apart. Bottles were observed getting close to pier and at 13:06, one rope reached the pier. Items were picked up
13:25	-	-			*Plastic items drifted to shore and had to be picked up and re-deployed. 13:25 marks the time of drop-off*
13:30	V	529	51.792, 4.775	51.794, 4.781	Observed in visual line-of-sight (2 cylinders and 1 bottle)
13:36	V	1092	51.787, 4.764	51.792, 4.778	

Due to the distance from the boat, and that the ropes tended to behave in a suspended manner rather than floating completely, it was not possibly to visually identify the colour of the ropes (see Figure 3-10). Where possible, the green or blue rope configurations could be identified based on the plastic items observed floating on the water.

At a distance of 100m away from the boat, 5 individual signals could be observed from the radar images, as illustrated in Figure 3-11. The transmission direction at 12:54 is roughly perpendicular to the ropes in the water. Based on the size of the plastic items attached to both ropes and its height above water when floating, it was possible that either the plastic bag (item #5) or the bubble wrap (item #2) were the items that could not be detected. From another camera image taken at 12:53, the plastic bag (item #5 of the green rope) could not be visually, leading to a higher likelihood that the sixth 'missing' signal corroborating with the total number of plastic items deployed was the plastic bag. Furthermore, the plastic bag could not be sealed completely, allowing water to enter the bag. It was thus possible the plastic bag behaved in a suspended manner as opposed to a completely floating object. However, the same applies for the bubble wrap as the 4 wooden items attached to it prevented it from being suspended within the water column but did not exclude water overtopping the bubble wrap and submerging it partially or completely. In case the bubble wrap had been truly detected, it is not possible yet to determine if the detection was due to the bubble wrap itself, or if the wooden blocks had played a role in contributing to the signal observed.

Figure 3-10: Image of the plastic items observed from the boat. Ropes cannot be seen in these images and the cloudy conditions did not allow clear visual identification of the other items within the plastic rope configurations.

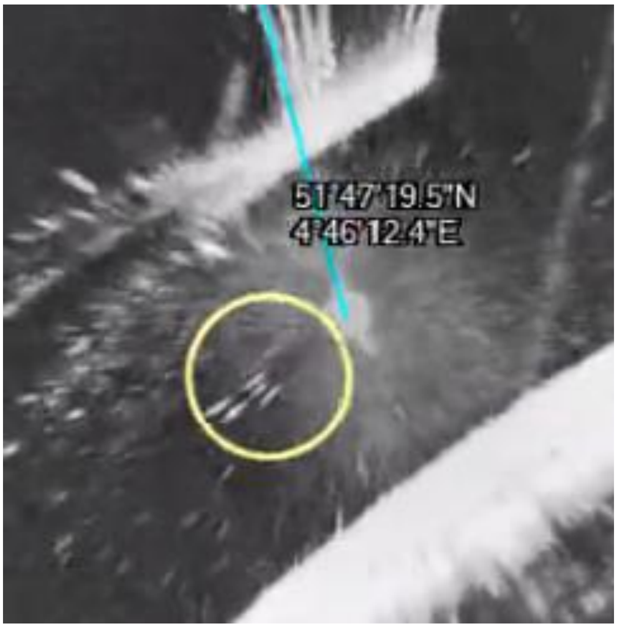

Figure 3-11: Radar image of the plastic items at 12:54 on 6th March 2020. 5 distinct signals could be observed approximately 100m from the radar. Using visual corroboration, the plastic signal was marked out manually (yellow circle). The coordinates in the image belong to the center of the yellow circle, in this case, the location of the plastic items.

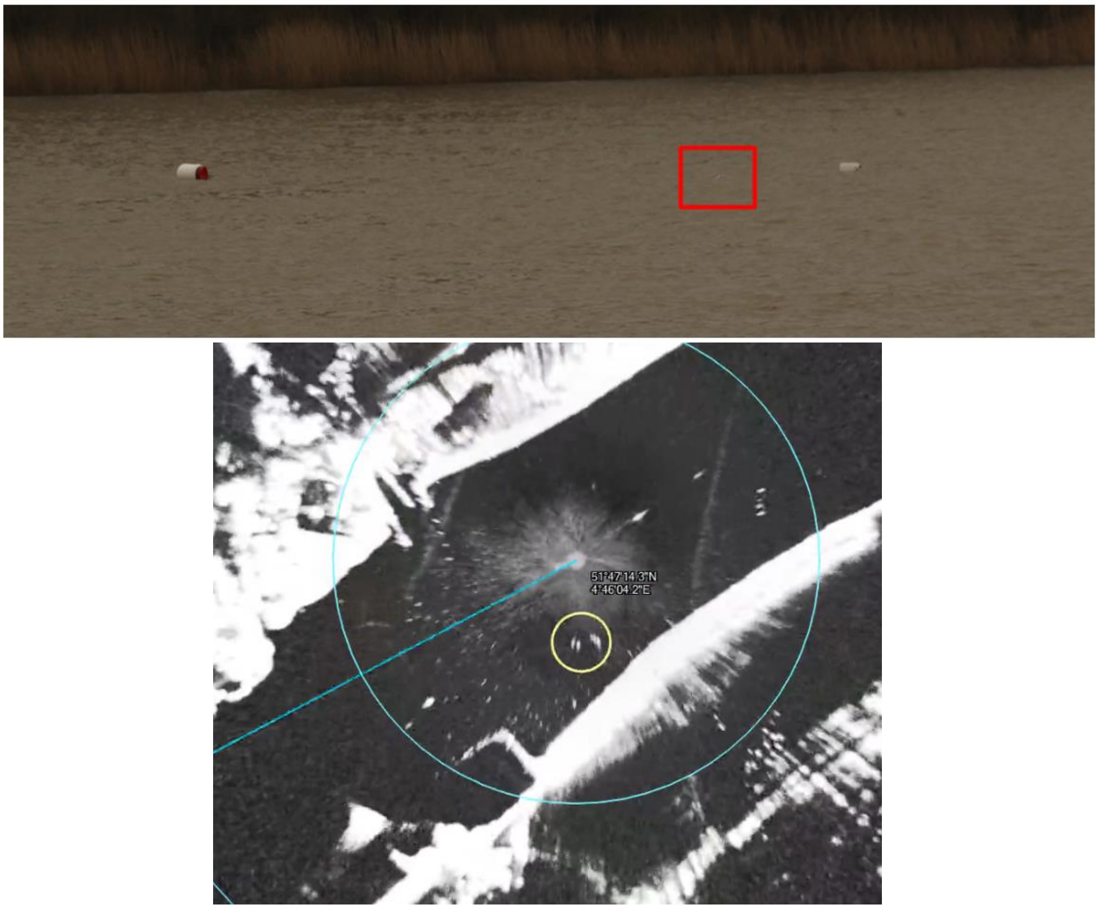

Figure 3-12: (Top) Camera image of the green rope configuration at 6 March 2020 13:00. The plastic bag cannot be seen well in this image, but is highlighted with the red rectangle. (Bottom) Radar image taken on 6th March at 13:00, same time as when the camera image was taken.

At 13:04, approximately 270m from the plastic items, the boat moved towards a more diagonal position relative to the ropes. As the heading of the image remained the same for both Figure 3-11 and Figure 3-13, the different position of the boat can be seen in Figure 3-13. Additionally, the individual signals observed had become less coherent, making it difficult to distinguish between the different plastic items. The change in the position of the boat resulted in the transmission direction switching from a perpendicular direction to a diagonal one relative to the rope configuration. In addition, the azimuthal resolution of the radar instrument may have played a role in the less coherent signal observed in the radar images.

Figure 3-13: Radar image from 6th March 2020 at 13:04. The additional bright spot to the left of the circle is the position of the buoy in the channel.

Due to the rapid drift of the ropes towards a jetty, the plastic items had to be picked up at 13:06 and later redeployed. Following redeployment, the plastics could be further detected at distances of 500m and 1km apart. At 500m, 3 distinct signals could be observed from the radar images (see Figure 3-14). The signals are 2 bright and big spots, and one small spot. As 5 signals were previously observed, it is possible that the two brighter signals observed might constitute two plastics sitting in the transmission direction consecutively, resulting in a brighter signal observed due to more backscatter. At a distance of approximately 1km apart (13:36), the plastics were still detected, presenting themselves as two small bright spots sitting closely together Figure 3-15. The plastics were last observed at around 1.1km distance, before the signal began drifting towards the river bank and disappearing from the radar images. Based on these findings, it can be concluded that at least 4 out of the 6 plastic items could be detected individually, while the 5th signal observed may have been an individual plastic item, or a combined signal of two plastic items. If the 5th signal were indeed an individual plastic item detected, it was more likely to have been the plastic bag rather than the bubble wrap. In the bottom figure of Figure 3-12, 5 signals present themselves, and corroborates to the same timestamp as the camera image (top) of Figure 3-12. The camera image shows two bottles, one bigger than the other, and between the bottles is an item that cannot be identified as bubble wrap or a plastic bag. When comparing with the rope set-up configuration (Figure 3-9), the item between two bottles is a plastic bag, i.e. the green rope. It is therefore much more likely that the 5th signal would be the plastic bag instead of the bubble wrap, based on the rope configuration, and identification of 5 signals at the same timestamp.

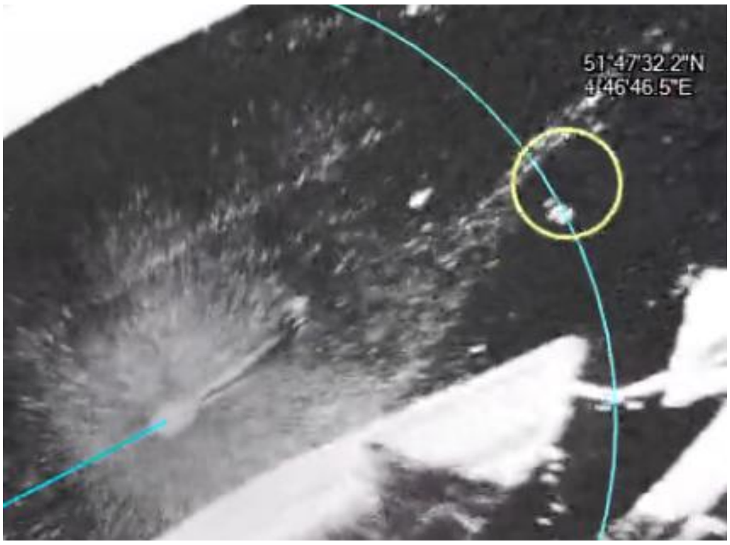

Figure 3-14: Radar image taken on 6th March 2020 at 13:30

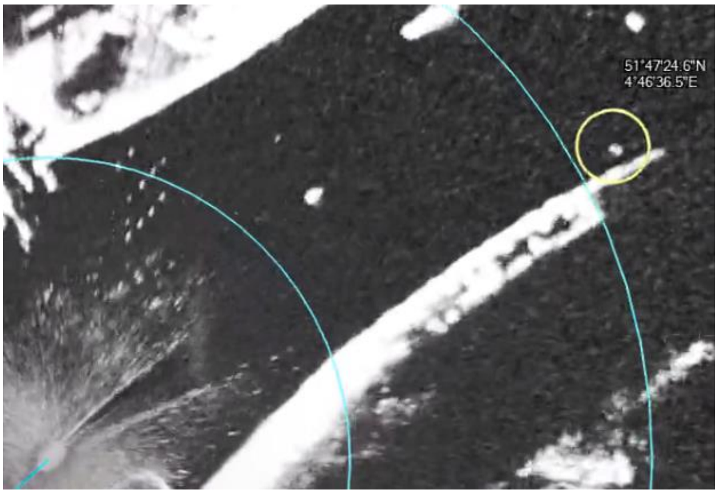

Figure 3-15: Radar image taken on 6th March 2020 at 13:36

3.4 Third campaign - 16th March 2021

3.4.1 General

The third campaign we used a larger number of (smaller) items than during the previous two campaigns. We released 6 items at three sites. For each site we carried out a series of detections from different detections. The specifications per item are given in Table 3.4 and photos of the items are presented in Figure 3-9: Pictures of the plastic items on the blue (item 1, 2 and 3) and green (item 4, 5 and 6) ropes.Figure 3-9.

Table 3.4: Details of the items detected during the third campaign

Item number	Description item	Material type	Length (m)	Height when flat (m)	Height above water surface (m)	Remarks
P1	White 5 l jerrycan	Plastic (PE)	0.28	0.13	0.13	
P2	White 2 l milk jar	Plastic (PE)	0.23	0.08	0.08	

P3	Green 1.5 l bottle	Plastic (PET)	0.33	0.08	0.08	
P7	Transparent 1.4 l bottle	Plastic (PET)	0.30	0.08	0.08	This item is similar as P2
P4	Green 0.5 l bottle	Plastic (PET)	0.22	*0.06*	*0.06*	
P5	Gold colored cylinder *Brugse Zot*	Can	0.32	0.10		Appeared not water proof: some water entered during the test, but not more than 20%
P6	White plastic bag	Plastic	0.63	<0.01	<0.01	Only partly above the water after release
P8	Yellowish block	Wood (varnished)	0.23	0.05		An metal eye was inserted to connect it to the rope
P10	White packaging form 1.5 l milk	Cardboard	0.24	0.07	0.07	

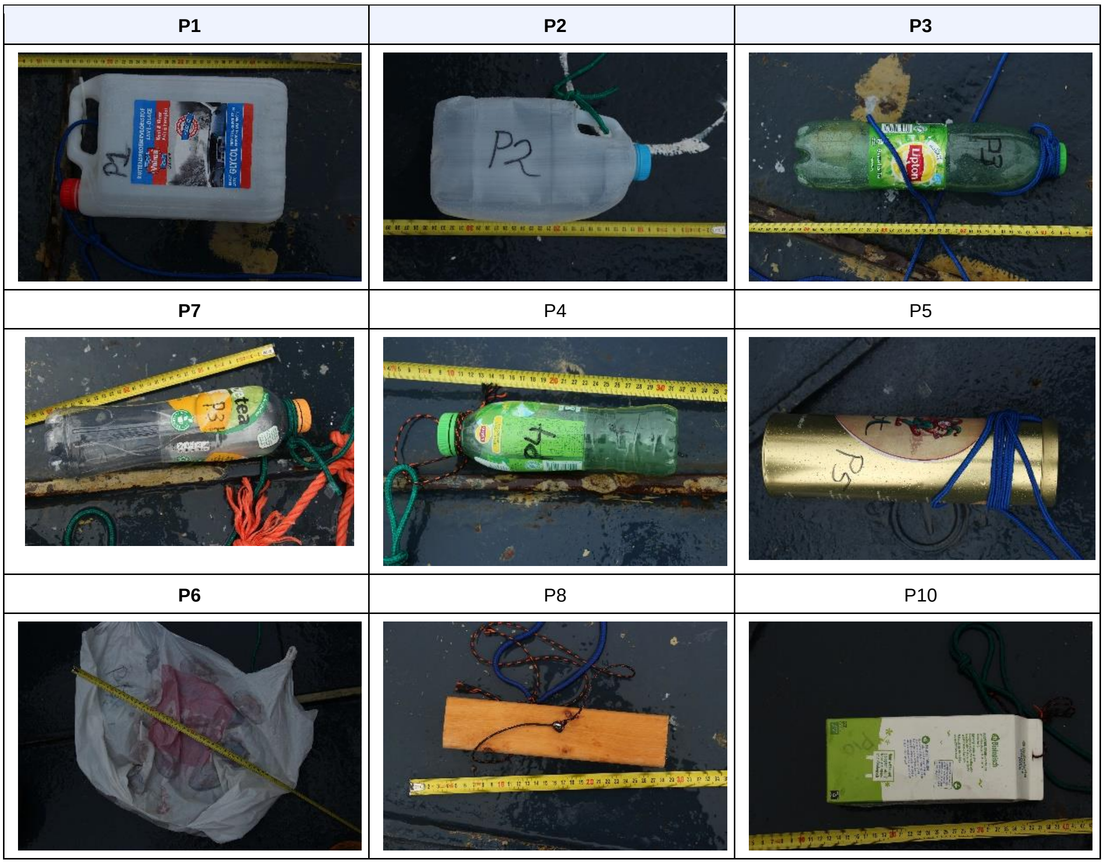

Figure 3-16: Photos of the items

In earlier campaigns we did not use anchors to make sure that the items were freely floating would not generate any disturbance of the water surface by the drag of the water on the item. Specific for this campaign is that we used small anchors to avoid that the plastic items would be blown into the river bank and could not be retrieved anymore. The anchor was attached to the first item out of three. We selected sites to release the items with limited flow velocity. No (small) waves or other water surface disturbance could be seen when we were close to the items to release or retrieve them.

3.4.2 Series 1

The first location where we released the two ropes was near the *Moerdijkbrug*. It appeared that the depth was limited (1-2 m). Additionally, a small oil spill was encountered, which was cleaned up by the monitoring ship largely before it arrived at the river bank. After the oil was cleaned up, the ropes were released with attached to the green rope items P2, P4 and P6, and attached to the blue rope items P1, P5 and P3 (Figure 3-17).

Item P2 attached to the green rope could be distinguished at 150 m. P4 (0.5 l plastic bottle) and P6 (plastic bag) could not be distinguished in the radar signal: they were not detected. The items attached to the blue rope were distinguished separately at 150 m (by zooming in to Figure 3-18) and, with some difficulty, at 220 m as well. Additional radar images can be found in appendix A.3.

Green rope	Blue rope
	

Figure 3-17: The items directly after they were released for series 1

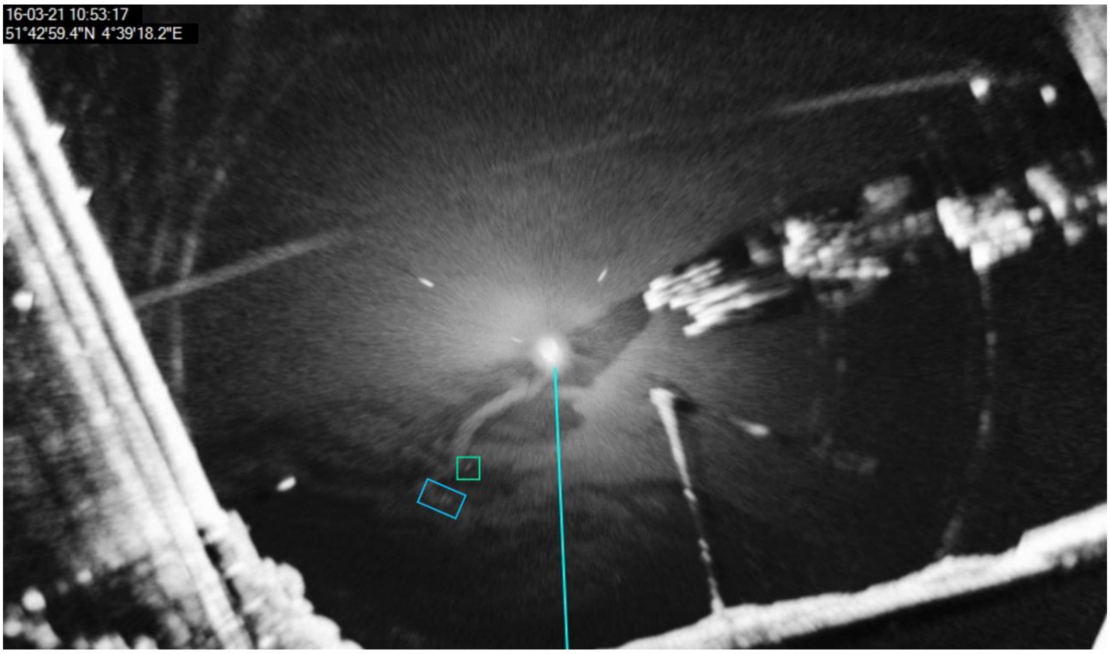

Figure 3-18: The signal of the items on the blue and green rope at about 150 m from the radar.

3.4.3 Series 2

The second location where the ropes were released was in the Merwede. The ropes were released with attached to the green rope items P2 and P3 (a third item was a bottle made of glass, which broke into pieces shortly before release of the rope), and attached to the blue rope items P1, P5 and P3 (Figure 3-19).

Item P2 attached to the green rope could be distinguished at about 150 m in some of the radar images. A boat passed during this observation, and perhaps the items only gave a reflection different than from water, when they were exposed on the waves. Therefore, we defined the detection of these items as intermittently. P4 (0.5 l plastic bottle) and P6 (plastic bag) could not be distinguished in the radar signal: they were not detected. The three items attached to the blue rope were distinguished separately at about 150 m and, with some difficulty, at about 220-250 m as well (Figure 3-20). Additional radar images can be found in appendix A.3.

Figure 3-19: Items after they were released for the green rope (left) and the blue rope (right); Note that only 2 items (with 20 m apart) were attached to the green rope.

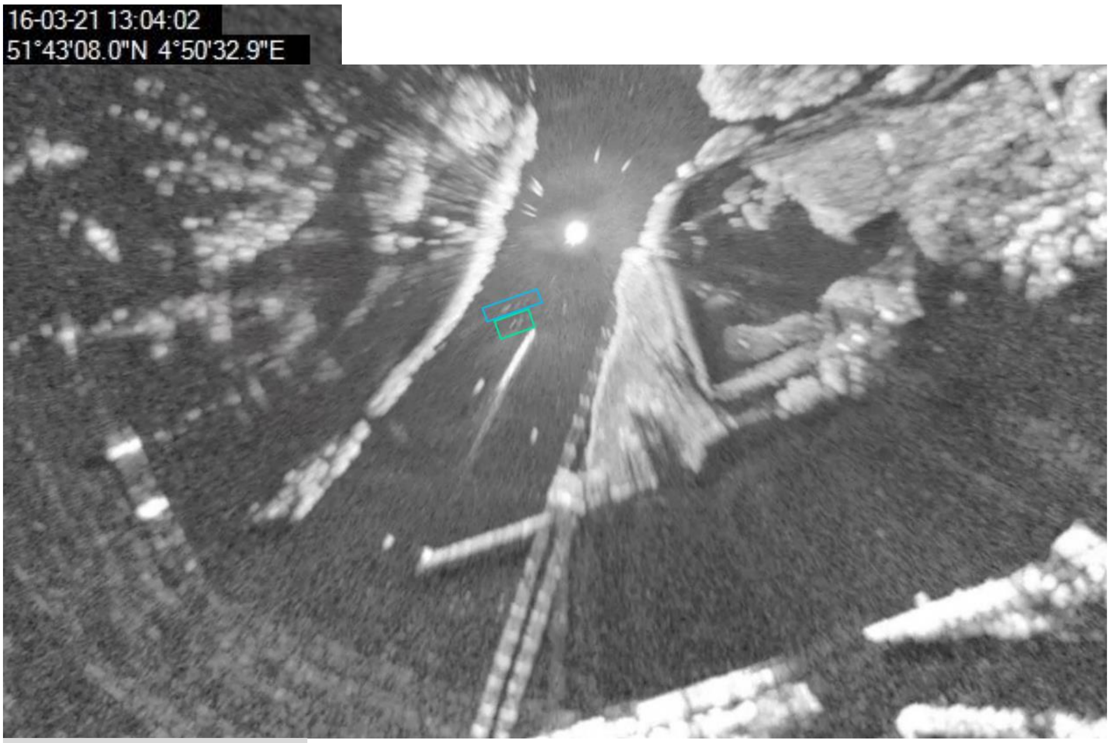

Figure 3-20: The radar signal when the boat was at 150 m (top) and 220-250 m (bottom), with the location of the ropes indicated by the rectangles.

3.4.4 Series 3

For this series, we released the ropes close to a river bank in a deep section, where commercial ships can be moored. The ropes were released with attached to the green rope items P2, P8 and P6, and attached to the blue rope items P1, P7 and P6. It appeared so deep that the anchor pulled item P1 under water. All items were not clearly detected for this series. Two reasons can explain this result: (1) the size of the items was relatively small or (2) the signal of the items did not stand out from the signal of the poles and the signal of the water. Since at least the larger item (P2) was detected in other series and not here, the poles are thought to be the main reason. Hence, we concluded that this series was not representative for an open river, and the results of this series were not considered in the remainder of this report.

Figure 3-21: Photo of all floating items, where P1 is not visible since it is submerged (top) and an overview of the location including large poles where commercial vessels can be moored (bottom)

3.5 Detection per item

As a summary, Table 3.5 presents the detection results of the second and third campaign (series 1 and 2), when the radar transmitted a vertically polarized signal and the items were about 10 m apart from each other attached to a rope. The largest items (jerry cans of 2, 5 and 19 l) were detected at 150 m, and sometimes up to 500 m. A bubble wrap with four wooden buoys was probably detected at 100 m, although it was not certain how flat it was on the water surface. Cylinder sized items (1.5 l empty PET bottle and a metal cylinder) were detected intermittently, which seemed to relate to waves generated by a passing commercial vessel.

Table 3.5: Summary of detection results per item over campaigns 2 and 3, when the items were separated 10 m apart on the rope

Item number	Description item	Length (m)	Height when flat (m)	Detected individually?	Max distance (m)	Remarks
1	19L jerry can	0.43	0.27	Yes	500	
2	Bubble wrap with four mini wooden buoys	1.34	<0.03	Yes	100	Assuming this item was detected (and not 5)
6, P1	White 5 l jerry can	0.28	0.13	Yes	150-500	
P2	White 2 l jerry can for milk	0.23	0.08	Yes	150	
3,4, P3	Green 1.5 l bottle	0.33	0.08	Yes	150	Intermittently
P4	Green 0.5 l bottle	0.22	0.06	No	-	
P5	Gold colored cylinder *Brugse Zot (metal)*	0.32	0.10	Yes	150	Intermittently
5, P6	White plastic bag	0.63	<0.01	No	-	Most likely not detected in both campaigns 2 and 3

4 Conclusion and future outlook

4.1 Answer research questions

1. *Can X-band radar detect floating plastic items, and if so, from what size are they able to?*
   Yes. An empty 1.5 l PET bottle and similar shaped items were detected individually at a maximum distance of about 100-150 m. A 5 l and 19 l jerry can were detected up to 500 m. An empty PET bottle of 0.5 l could not be detected with the settings used. Items attached to one rope were detected as one grid cell up to 1.5 km away from the radar.

2. *Can X-band radar be used to track movement of floating plastic items, thus monitoring the behaviour of plastic transport?*
   Yes, we tracked at least 3 out of 6 items using a vertical polarisation in the transmission, when after they were released without anchor (second campaign). For the horizontal transmission and horizontal receive polarisation radar we could track the 19 l container and larger items as well, but over a shorter distance (first campaign).

3. *Can floating plastic items be distinguished from other material types?*
   Not tested thoroughly. A metal can had a similar reflection as a 1.5 l PET bottle. Recommendation is to test this structurally.

4. *What is the effect of variations in weather and flow conditions during the survey on the above research questions?*
   Not tested thoroughly. Recommended to repeat tests during different conditions, especially wind conditions seem important.

4.2 Outlook for detecting floating plastic items

To the extent of the authors knowledge and based on available literature, this is a pioneer study on the potential for X-band radar to be used to detect floating plastics as a monitoring tool. The detection of floating plastics, even up to individual items, was shown to be possible using such an instrument. However, some of the plastics used in the measurement campaigns might not be representative of real-world environments. The 19L jerry cans, for example, are much less commonly found in rivers than plastic bottles or plastic bags. In addition, the plastics tested in the measurement campaign were clean and free of algae scum. Plastics that have been in rivers longer may develop a biofilm around it, affecting the dielectric constant and backscatter behavior of plastics. Additionally, the position of the items was known (approximately) when analyzing the radar signal. In order to be able to detect floating plastics, and distinguish them from e.g. birds, dedicated post-processing methods need to be developed.

Additionally, the finding that a vertical transmission allowed the signal of floating plastics to be detected further away than a horizontal transmission will be able to inform future measurement campaigns for detecting floating plastics using such a device. At a given distance the vertical transmission results in a better signal than for horizontal transmission radars. Although individual plastic items could be detected during the second and third measurement campaigns, this was largely dependent on the spacing between the plastic items on the rope and the transmission and azimuthal resolutions of the radar instrument itself. From the measurement campaigns, the signal weakens considerably with distance from the instrument. At 270m distance from the boat, the plastics need to be minimally 4m apart on a line perpendicular to the transmitted radar signal, since that is the azimuthal resolution of the radar.

Aiming to detect plastics with a standard X-band radar such that existing radars can be used along the river (and possibly from ships), we recommend to include both horizontal and vertical polarized radar settings in upcoming experiments. Standard X-band radars have horizontal polarization. Buoys strongly scatter when receiving a horizontally polarized signal. Therefore, for shipping it is obliged to use a horizontal polarized radar. The X-band radar used for this experiment can be set to one of both polarisations. Although the signal of an item at some distance is not as clear in comparison with vertical polarization, the horizontal polarized radar has the advantage that more data is available. We plan to use both polarisations in future experiments to answer the research questions in more detail.

4.3 Other applications

Besides detecting plastics, X-band radar could also be used to determine bed level (including bedform height) in two ways:

1. By generating large enough waves (e.g. with a boat), bathymetry can result from the radar signal, using an inverse modelling approach;
2. By analyzing the radar signal returning from capillary waves. In order to have capillary waves, the wind speed needs to be 1 m/s or larger. Flow over the bathymetry modulates the signal from the capillary waves. From the modulations it may be possible to obtain bathymetry.

Both methods need to be worked out further. Results showing patterns similar as the bathymetry have been obtained and show the potential. When bathymetric maps can be obtained at two subsequent moments in time, migration of bedforms or deposition of sediment/plastic can be estimated for the period in between the maps.

5 References

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A Appendix

A.1 4th March 2020

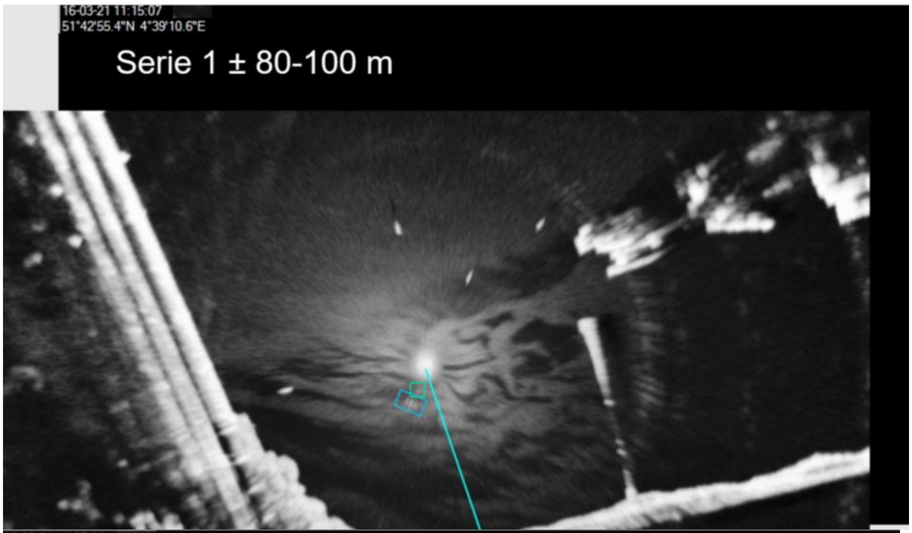
Time (UTC +1)	Ship latitude (degrees)	Ship longitude (degrees)	Plastic marker latitude (degrees)	Plastic marker longitude (degrees)
03/04/2020 14:15:22	51.8116178988782	4.87326291584211	51.8121557222274	4.87435633458826
03/04/2020 14:16:06	51.8106276153551	4.87227659675901	51.8121574067417	4.8743916837067
03/04/2020 14:16:50	51.8100354031972	4.87142268784143	51.812105581622	4.87442083028046
03/04/2020 14:17:46	51.8101631617004	4.87157829832301	51.8121531151931	4.8745151027145
03/04/2020 14:25:24	51.8098389997113	4.87096744592467	51.8118310370564	4.87418261031587
03/04/2020 14:27:25	51.8098236030635	4.87084865966939	51.8118280406608	4.87418120500343
03/04/2020 14:29:16	51.8097880044398	4.87080259364026	51.8118312412561	4.87410800604538
03/04/2020 14:30:42	51.8098166267504	4.87081670377918	51.8118020902875	4.87405881621809
03/04/2020 14:31:58	51.8092079718781	4.86986929466226	51.8117119849879	4.8740265460398
03/04/2020 14:33:18	51.8084172802526	4.86871414862554	51.8116584368471	4.87408865370327
03/04/2020 14:35:03	51.8082592345105	4.868466550394	51.8116196080152	4.87406168200109
03/04/2020 14:36:22	51.8081916464535	4.86839589596522	51.8116115018462	4.87400382086045
03/04/2020 14:42:41	51.8079206810288	4.8679682077685	51.8114682990129	4.87390146561559
03/04/2020 14:47:03	51.8078707844813	4.86796138789659	51.8114949143451	4.87392498712826
03/04/2020 14:48:43	51.8070382660174	4.86654491277701	51.8113942790266	4.87387578118115
03/04/2020 14:50:09	51.8058312187955	4.86422075738935	51.8113082395368	4.87403971270881
03/04/2020 14:51:20	51.8050540937454	4.86278179601214	51.8112606826158	4.87418833633636
03/04/2020 14:52:18	51.8050211326118	4.86277577180542	51.8112940635955	4.87409601855743
03/04/2020 14:57:15	51.8048004995979	4.8623601668873	51.8113519704869	4.87420371802172
03/04/2020 14:59:12	51.8032435580342	4.85758373606323	51.8112725719468	4.87416149126871
03/04/2020 14:59:42	51.8026247618059	4.85613719024677	51.8111391487766	4.87401941724176
03/04/2020 15:10:21	51.8035622607191	4.85868909995712	51.8112311811783	4.87417342169077
03/04/2020 15:12:02	51.8050265116092	4.86212822309406	51.8115280028692	4.87431413456435
03/04/2020 15:13:09	51.8060647693944	4.86435225178303	51.8115062461853	4.87428880326028
03/04/2020 15:16:21	51.8095217649811	4.87008750301456	51.811751985311	4.87403004663908

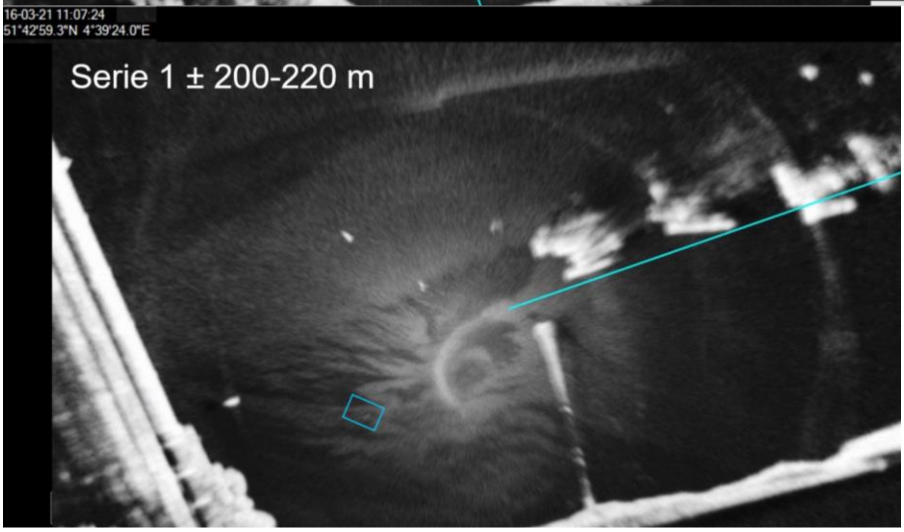
A.2 6th March 2020

Time (UTC +1)	Ship latitude (degrees)	Ship longitude (degrees)	Plastic marker latitude (degrees)	Plastic marker longitude (degrees)
03/06/2020 12:51:42	51.7916645948726	4.77259510934653	51.791483766105	4.77215587938316
03/06/2020 12:52:31	51.791662577858	4.77267226302351	51.7913095060659	4.7720806335199
03/06/2020 12:53:38	51.7914305661123	4.77260171139671	51.7909271100024	4.77153930837819
03/06/2020 12:54:30	51.7912602697731	4.77224415978825	51.7906931869141	4.77116452643516
03/06/2020 12:55:56	51.7910319391726	4.77168778167919	51.7903179576269	4.77069390062912
03/06/2020 12:56:51	51.7908566808127	4.7714032126735	51.7900398637782	4.77028953221792
03/06/2020 12:58:00	51.7909427106461	4.770879484822	51.7898198444052	4.76997920275049
03/06/2020 12:59:10	51.7909787350882	4.7691090428265	51.7894648718453	4.76961892812169
03/06/2020 13:00:15	51.7907555489518	4.76888012157982	51.7892268700488	4.76913393539255
03/06/2020 13:01:21	51.7903968679133	4.76844820649474	51.7889972214683	4.76877046377059
03/06/2020 13:02:07	51.7900557523543	4.76798403137925	51.7887588381761	4.76860372658736
03/06/2020 13:03:16	51.7899010593754	4.76573237760114	51.7883085820886	4.76811012685552
03/06/2020 13:04:18	51.7898990297938	4.76533136357736	51.7880547756712	4.76772161613892
03/06/2020 13:05:26	51.7898038095	4.76525144993386	51.7877814743441	4.76736678266191
03/06/2020 13:06:37	51.7895448599311	4.76501274338441	51.787430338156	4.76681022900921
03/06/2020 13:09:08	51.7865679215447	4.76536644699045	51.7869033236825	4.76592358845137
03/06/2020 13:26:04	51.7954068586407	4.7812111478265	51.7958261085902	4.78292605523302
03/06/2020 13:26:57	51.7943645626498	4.7788964396452	51.795495559774	4.78263293455706
03/06/2020 13:27:57	51.7937323049411	4.77756641469155	51.7952214197832	4.78211319509649
03/06/2020 13:28:55	51.7933923110696	4.77718430361522	51.7948809994183	4.78167434900919
03/06/2020 13:30:07	51.7924845928442	4.77533501526382	51.7943577695303	4.78098924356335
03/06/2020 13:31:00	51.7919597152739	4.77421481096463	51.7941529700898	4.78079853016124
03/06/2020 13:31:54	51.7917411476487	4.77397871857498	51.7937699027558	4.7803469672387
03/06/2020 13:33:11	51.7916961827269	4.77305746197714	51.7934237337427	4.77970203052976
03/06/2020 13:34:03	51.7910063056192	4.77083170119699	51.7930429803583	4.779221437912
03/06/2020 13:34:53	51.789728026554	4.76830947724307	51.7926833574485	4.77887680736596
03/06/2020 13:35:51	51.7882107502789	4.76542794917756	51.7923327079708	4.77839200539756
03/06/2020 13:36:31	51.7874241494311	4.764157365777	51.7922642266045	4.77822688376253
03/06/2020 13:38:27	51.7874780853964	4.76539810234553	51.7917482102161	4.77769674478247

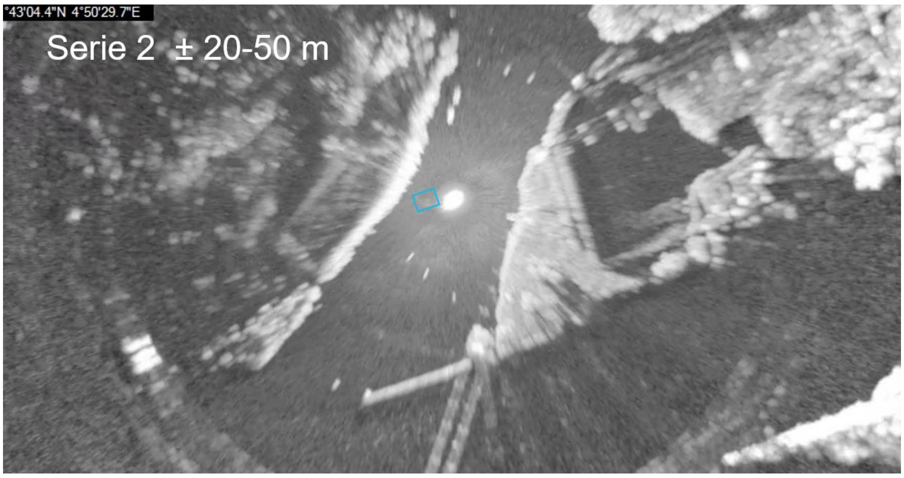
A.3 Radar images 16th March 2021

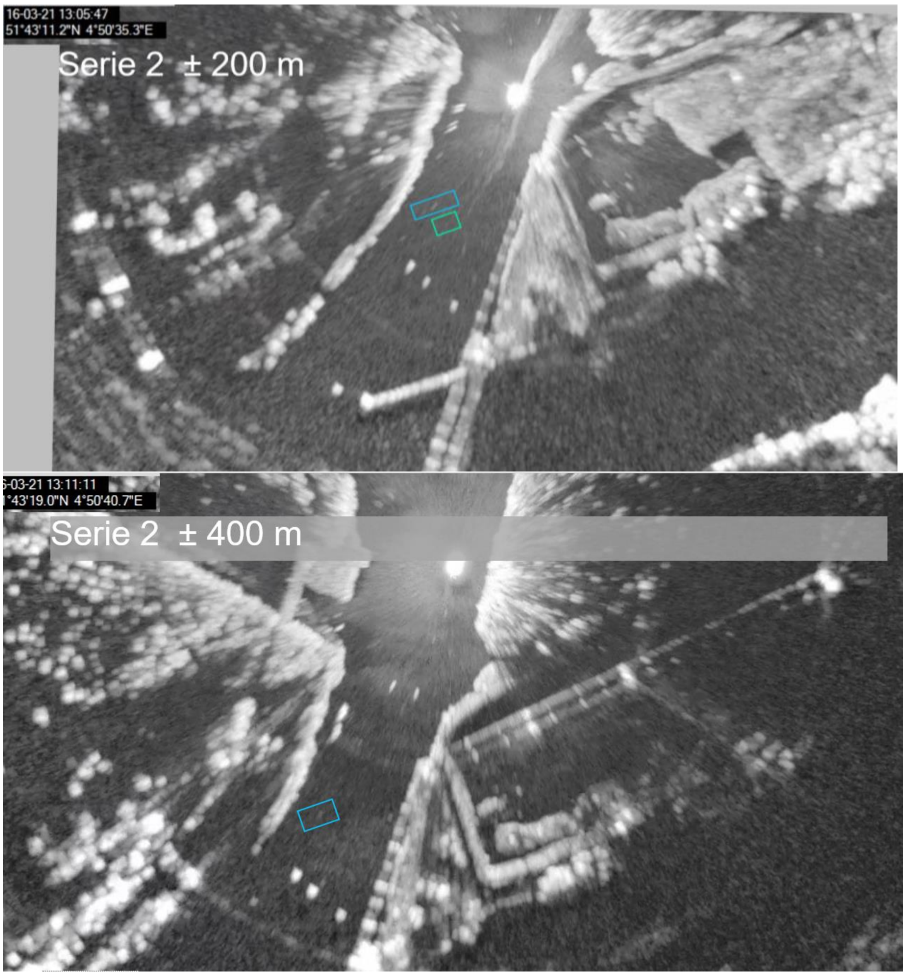
A.3.1 Series 1





A.3.2 Series 2




16-03-21 13:05:47
51°43'11.2"N 4°50'35.3"E
Serie 2 ± 200 m
Serie 2 ± 400 m

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