A controlled ground-based experiment to assess the capabilities of GNSS-R for marine litter detection in a flume

Amadeu Gonga[1,2] Adrian Perez-Portero[1,2], Adriano Camps[1,2,3], Daniel Pascual[4] , Anton de Fockert[5] , and Peter de Maagt[6]

1. CommSensLab – UPC, Dept. of Signal Theory and Communications, Universitat Politècnica de Catalunya – BarcelonaTech, E-08034 Barcelona, Spain
2. Institute of Space Studies of Catalonia (IEEC) – CTE-UPC, E-08034 Barcelona, Spain
3. ASPIRE Visiting International Professor, UAE University, CoE, POBox 15551 Al-Ain, UAE
4. Deimos Space UK Ltd, United Kingdom
5. Deltares, Delft, the Netherlands
6. ESTEC, Noordwijk, the Netherlands

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Departament de Teoria del Senyal i Comunicacions

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Introduction

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- Over **14 million tons** of plastic end up yearly in the ocean. Due to currents and gyros, freely floating plastic debris end up forming large extensions of garbage patches[1].
- Recent works[2] have studied the potential of GNSS-R to detect marine litter. The main hypothesis seems to be:
  1) Plastics foster the appearance of biofouling
  2) This increases the water surface tension
  3) The increased surface tension dampens the waves
  4) A sudden dampening affects GNSS-R observables

Amadeu recovering some of the plastics used in one of the tests at Deltares

- The ESA GLIMPS (Global Monitoring of Microplastics using GNSS-R) project, led by Deimos Space UK together with the Universitat Politècnica de Catalunya.
  - Conducted a GNSS-R experiment in 2021 in the Deltares' Atlantic basin, a controlled water flume in Delft, The Netherlands.
  - Studied the potential of GNSS-R for marine litter detection in controlled conditions
  - One of many teams employing a variety of remote sensing techniques.

[1] Lebreton, L.; Slat, B.; Ferrari, F.; Sainte-Rose, B.; Hajbane, S.; Cunsolo, S.; Schwarz, A.; Levivier, A.; Noble, K.; Debeljak, P.; et al. Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Sci. Rep. **2018**, 8, 4666.
[2] Evans, M.C.; Ruf, C.S. Toward the Detection and Imaging of Ocean Microplastics With a Spaceborne Radar. IEEE Trans. Geosci. Remote Sens. 2022, 60, 4202709.

Indoors GNSS-R Geometry Set-Up - Introduction

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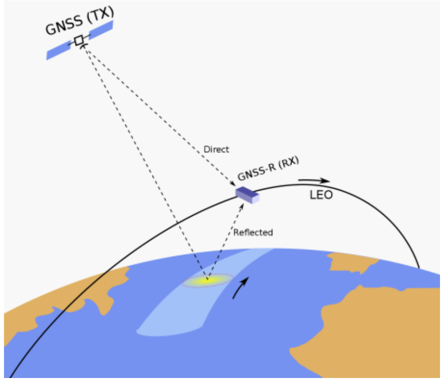
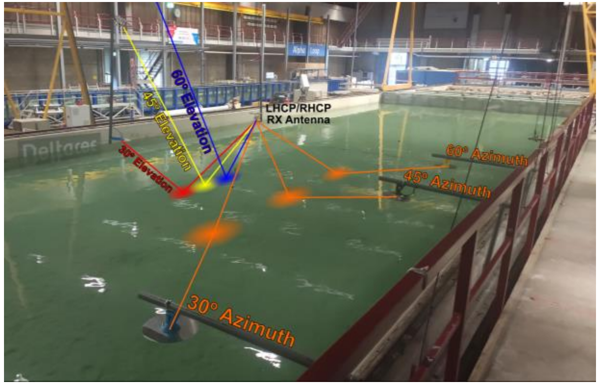


Conventional GNSS-R



GNSS-R set-up built at Deltares

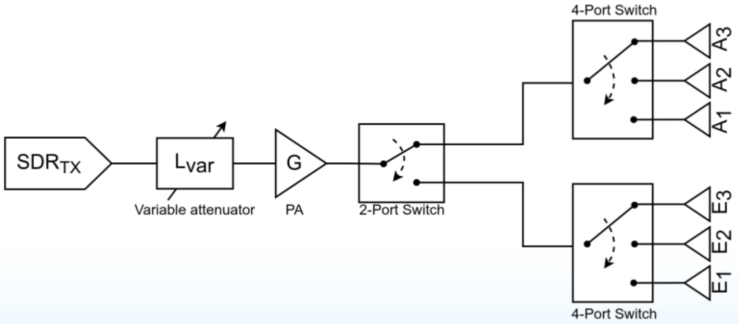
- Geometry of a GNSS-R scenario is difficult to simulate in a closed space and constrained by the location of the flume.
- There were also other requirements that involved minimizing the interference to the waves’ patterns (underwater supports), and to other teams performing their experiments (metallic surfaces close to the plastics).
- Other quality-diminishing factors such as an uncontrolled RF spectrum and severe multi-path were observed.

Indoors GNSS-R Geometry Set-Up - Transmission

- Transmission side
  - In order to simulate different grazing angles and elevations, multiple transmitting antennas are used, connected to the same SDR, with variable attenuations and a switching matrix to decide the current transmission path.
  - The transmitted signal includes synchronization beacons and a synthetic L1 C/A signal with SVs 16, 21, 29, and 31, recorded from a vector signal generator at a power level of -81 dBm.
  - All antennas used were COTS patch antennas except the ones used at 45º which were manufactured in house.

	Angle [º]	Frequency [MHz]	Polarization	Active/Passive
Elevation	30	1540 - 1610	RHCP	Passive
	45	1490 - 1700	RHCP/LCHP	Active
	60	1540 - 1610	RHCP	Passive
Azimuth	30	1540 - 1610	RHCP	Passive
	45	1530 - 1580	RHCP/LHCP	Active
	60	1540 - 1610	RHCP	Passive

Transmission antennas' specifications



Transmitter block diagram

Indoors GNSS-R Geometry Set-Up - Reception

- Reception side
  - Two patch antennas were used; one upward oriented (Up-looking) and an other downward oriented (Down-looking).
  - Due to limitations of the system, we could not implement a single receiver with three or more coherent reception ports. For this reason, two independent SDR were used.
  - The up-looking antenna was connected to a one-channel SDR for down-converting and sampling the received signal at a rate of f_s=2.5 MSps.
  - The down-looking antenna was connected to a two-channel SDR for down-converting and sampling the received signal at a rate of f_s=2.046 MSps.

	Frequency [MHz]	Polarization	Active/Passive
Up-looking	1540 - 1610	RHCP	Passive
Down-looking	1500 - 1600	RHCP/LHCP	Active

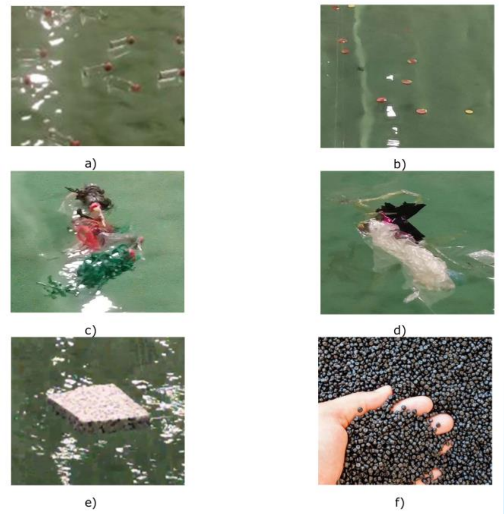
Reception antennas' specifications

Overview of the setup built at Deltares

Experiments performed

- The Atlantic basin flume could generate both periodic sinusoidal-shaped waves, or a more realistic JONSWAP spectrum which takes into account wind effects or wave-to-wave interactions.

Type	Spectrum	Capillary	Amplitude [cm]
Regular	Sinusoidal	No	5
			9
			12
			17
		Yes	5
			9
			12
			17
Irregular	JONSWAP	No	5
			9
			12
			17
		Yes	5
			9
			12
			17



- Multiple types of plastics were used, and the response of the system to each type (and concentration) was analyzed.

Methodology

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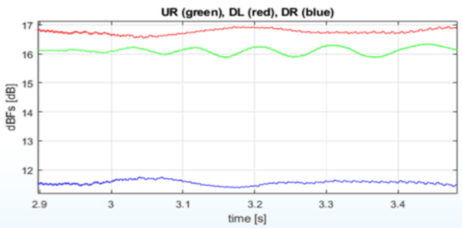
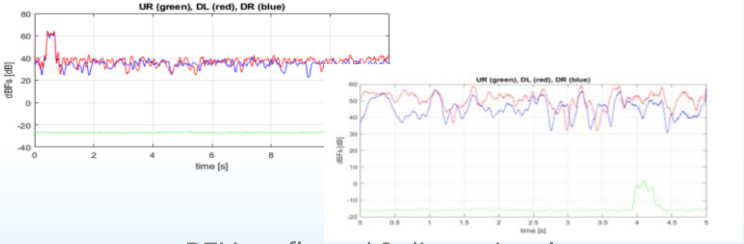
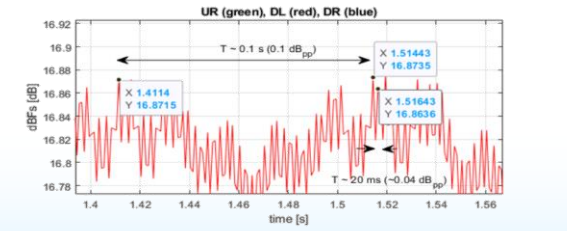
- 123 files analyzed
- Processing steps:
  - **Large CN0** (35-50 dBHz) allows for short integration times: T_{coh} = 1 ms, N_{inc} = 1
  - **Relative calibration** using flat water surface (known reflection coefficients)
  - Data screening:
    - **Multi-path**: P_{dir} not constant (up-looking antenna), $P_{ref}(P_{dir})$ not an horizontal line
    - **RFI**: either in up-looking and/or down-looking antennas
  - **Computation of DDM peak**: modulus (power) and phase saved for RHCP up-looking, and LHCP & RHCP down-looking antennas



Multi-path



RFI in reflected & direct signals



50 Hz EMI in reflected signal

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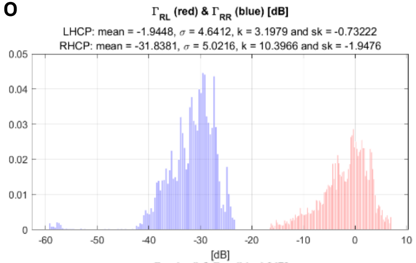
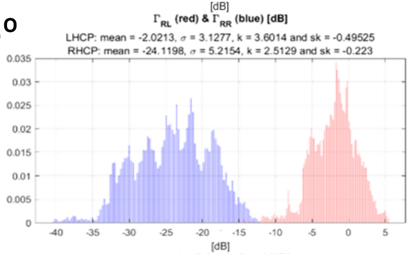
- Effect of the incidence angle on the distribution of the reflection coefficient.

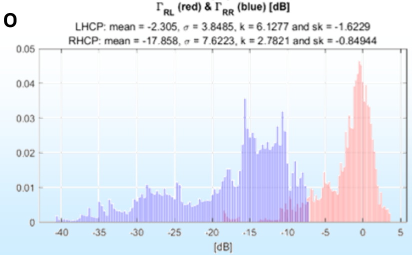
30º



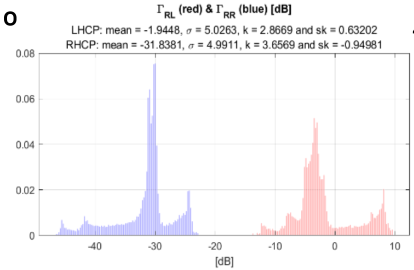
45º



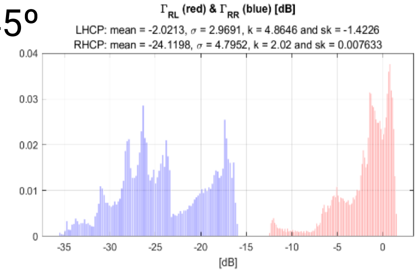
60º



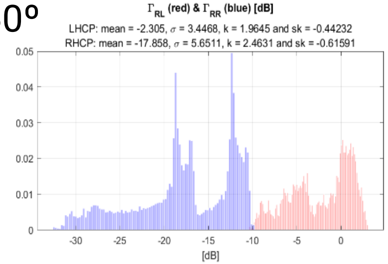
30º

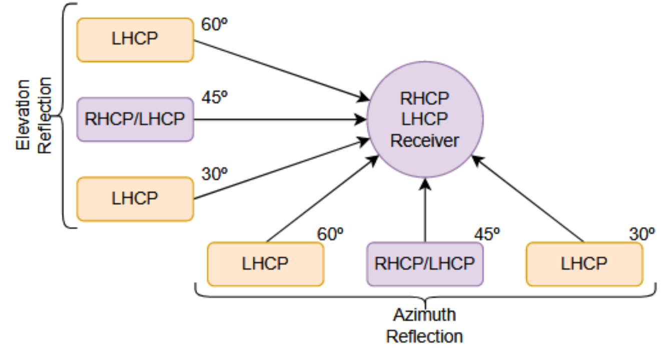


45º



60º





Results - Baseline

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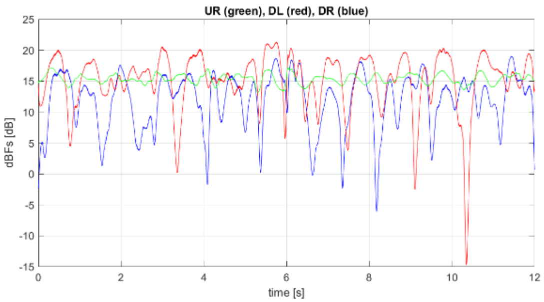
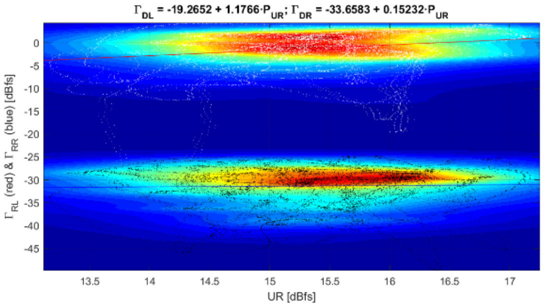
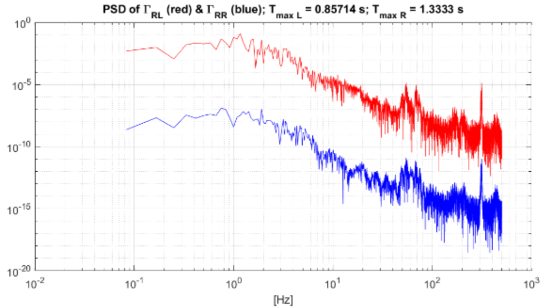
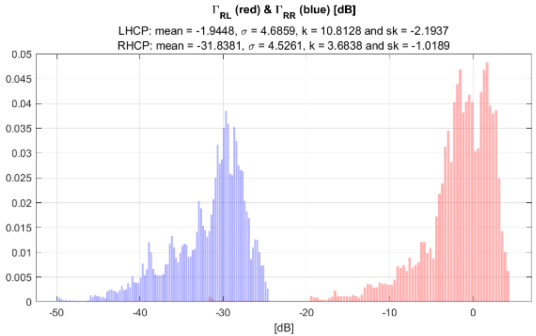


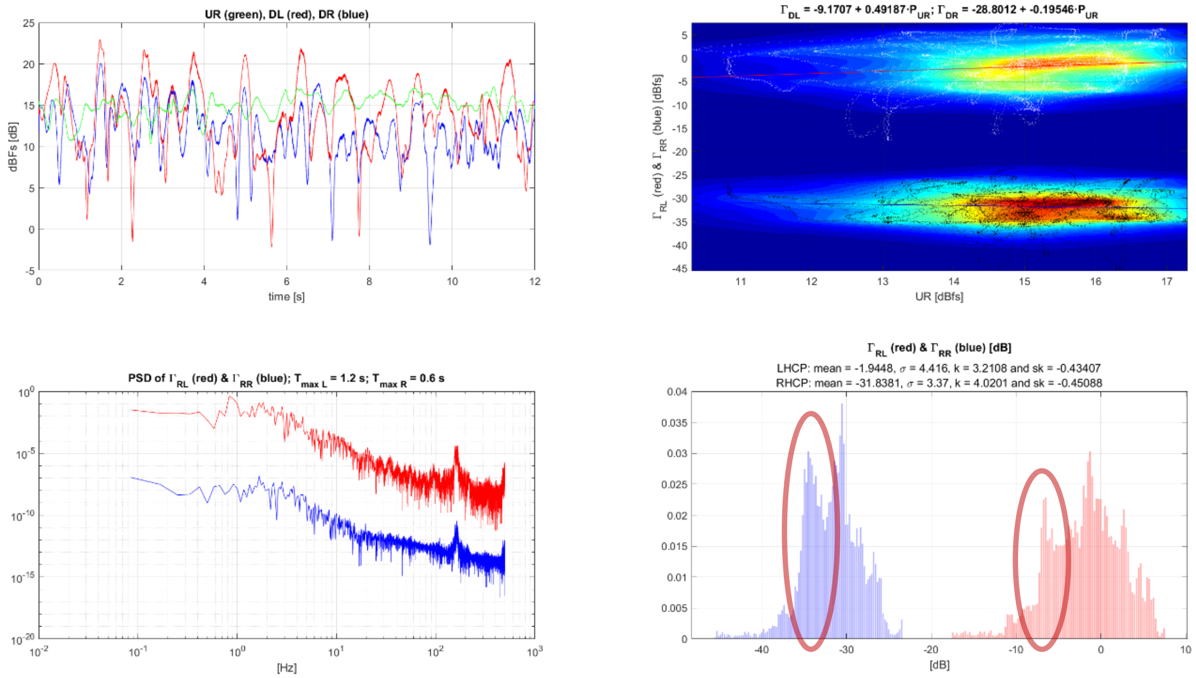






- No plastic, rough water surface

Results - Baseline



- No plastic, rough water surface, with capillary waves

Results - Plastics

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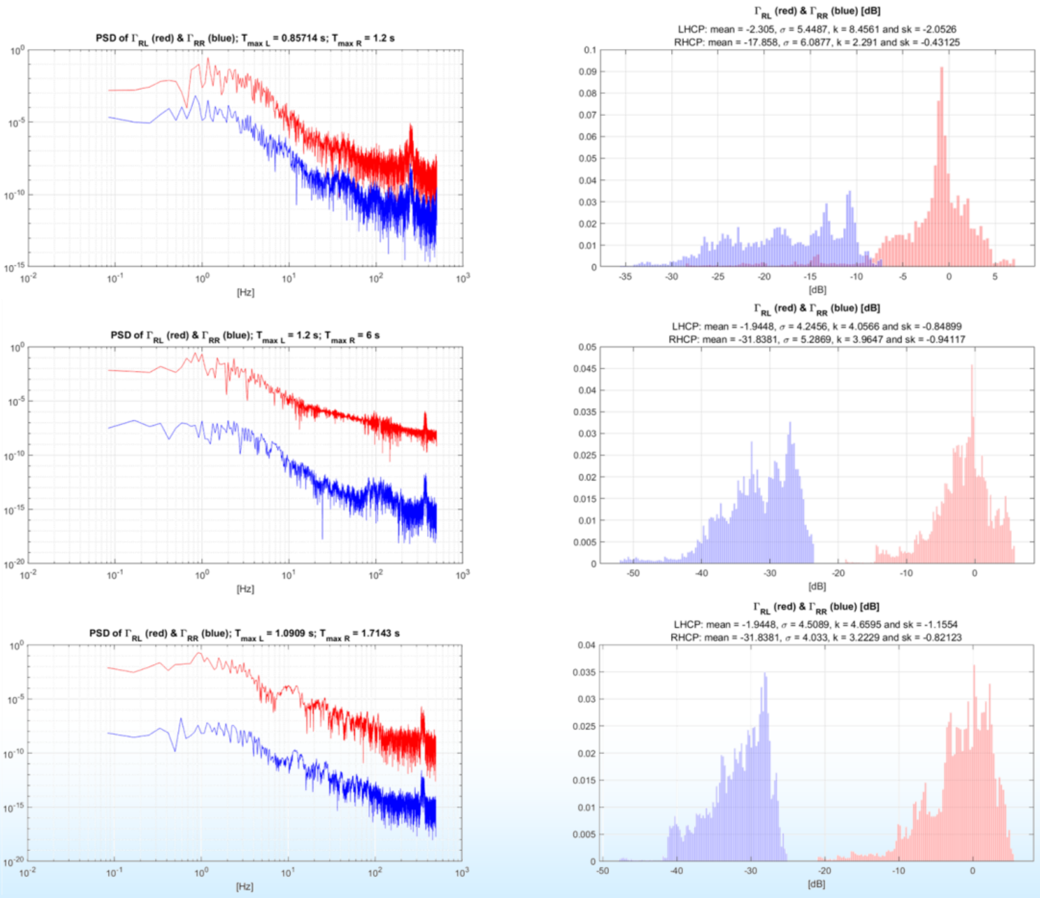
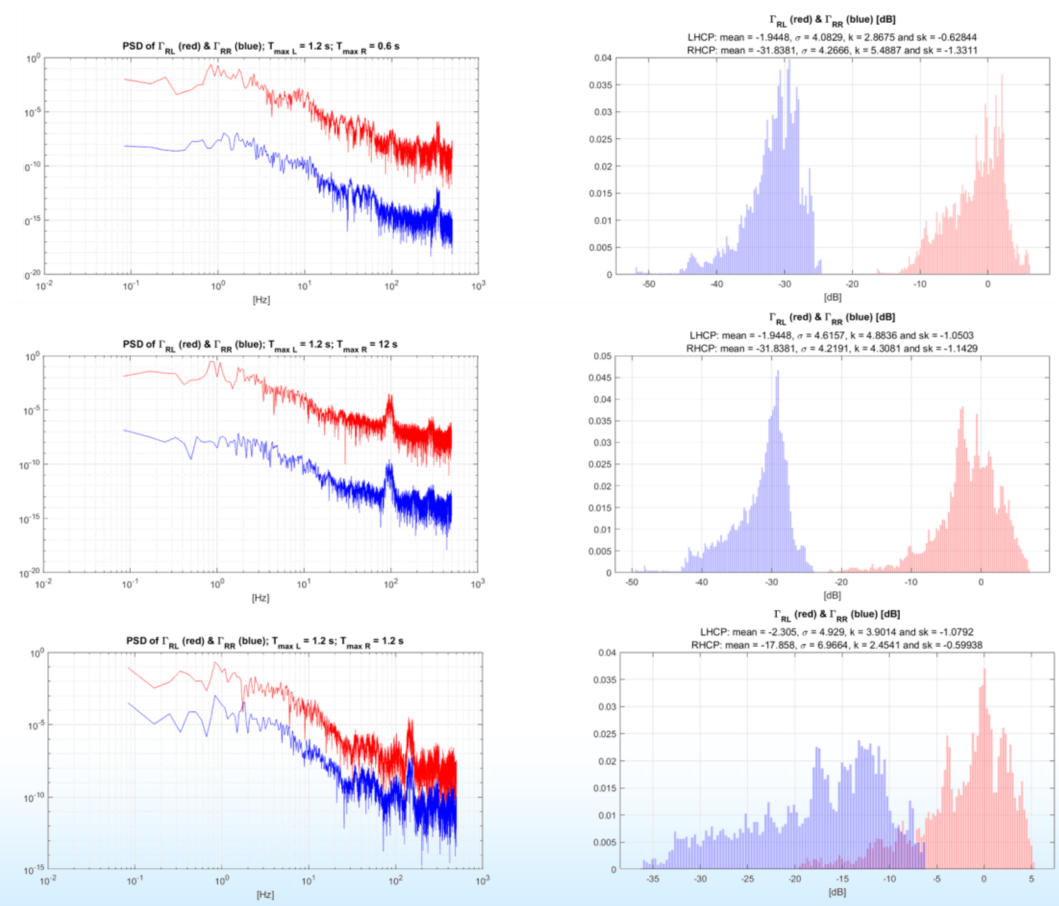


- Bottles and fixed net

- Bottles

- Marine litter (nets)

Results - Plastics



- Marine litter (bags)

- Marine litter (caps & lids)

- Straws

Results - Summary

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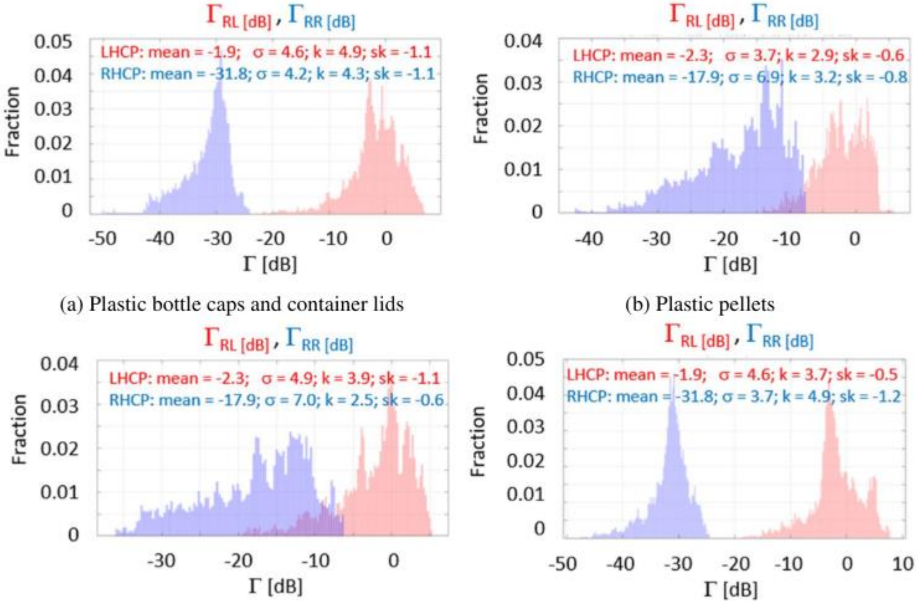
- Results show that the different plastics resulted in different distributions of both the Right-to-Left and Left-to-Right polarizations.
- The statistical analysis on the different scenarios showed that, although very faint, a difference between them could be observed over long experiments.
- Since most changes are marginal, a statistical analysis was performed both for the amplitude and phase of the reflection coefficients, and statistical descriptors are used as an indication.



(a) Plastic bottle caps and container lids

(b) Plastic pellets

(c) Drinking straws

(d) Styrofoam chunks

Results – Summary table

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Scenario	Amplitude	Phase
Clean water (flat/rough)	Surface roughness ↑ ⇒ $\sigma(\Delta\Gamma_{RL})$ ~ -9 dB Capillary waves ↑ ⇒ $\sigma(\Delta\Gamma_{RL})$ ~ - 1-1.5 dB Kurt varies in both cases	Sharp decrease $\sigma_{\angle\|\Gamma RL\|}$ with increasing rms height and presence of capillary waves Kurt and Skew: ↑ long waves ↑↑ long and capillary waves
Clean water (sin/JONSWAP)	Different temporal behavior $\sigma(\Gamma_{RL\ Jonswap}) < \sigma(\Gamma_{RL\ sinusoidal})$ by ~0.2-0.4 dB	$\sigma_{\angle\|\Gamma RL\|}$ smaller for sinusoidal No clear trend
Bottles and fixed net	$\sigma(\Delta\Gamma_{RL})$ ↑ ~ 2.5-3 dB with net and bottles, ~ 0.4 dB with net only Kurt ↑	$\sigma_{\angle\|\Gamma RL\|}$ ↑ 0.6°- 0.8° Marginal effect on other observables
Straws	$\sigma(\Delta\Gamma_{RL})$ ↓ by ~2-2.5 dB @ 30° ↑ by ~0.8 dB @ 60°	$\sigma_{\angle\|\Gamma RL\|}$ ↑: 0.7-0.8 °
Pellets	$\sigma(\Delta\Gamma_{RL})$ ↑ ~0.8-1.2 dB @ 30° and 45° Kurt ↑ ~2 @ 30° and 45°	$\sigma_{\angle\|\Gamma RL\|}$ ↑ by ~0.2° and ~1.1° @30° and 45° ↓ by ~4.5° @ 60°
Bottles	$\sigma(\Delta\Gamma_{RL})$: ↑ by 0.8 dB	Marginal
Marine litter (food wraps and bags)	$\sigma(\Delta\Gamma_{RL})$: ↓ by 0.8 dB at 5 cm rms ↑ by 1.8 dB at 9 cm rms ↓ by 0.4 dB at 17 cm rms Capillary waves damp increase of reflectivity fluctuations	$\sigma_{\angle\|\Gamma RL\|}$ ↓ by ~1.4° @ 5 cm rms, ↑ by ~1.1° @ 9 cm rms and ↓ by ~0.3° @ 17 cm rms
Marine litter (nets)	$\sigma(\Delta\Gamma_{RL})$: ↑ by 1.4 dB	$\sigma_{\angle\|\Gamma RL\|}$ ↑: 1.6° @ 30°
Styrofoam	$\sigma(\Delta\Gamma_{RL})$: ↑ by 0.7 dB	$\sigma_{\angle\|\Gamma RL\|}$ ↑: 0.5° @ 30° (marginal)
Caps and lids	$\sigma(\Delta\Gamma_{RL})$: ↑ by 0.4 dB Capillary waves damp increase of reflectivity fluctuations	$\sigma_{\angle\|\Gamma RL\|}$ ↑: 0.9° @ 30° 1.7° if capillary waves
Nets	$\sigma(\Delta\Gamma_{RL})$: ↑ by 0.6 dB	$\sigma_{\angle\|\Gamma RL\|}$ ↑: 0.3° @ 30° (marginal)

Gonga, A.; Pérez-Portero, A.; Camps, A.; Pascual, D.; de Fockert, A.; de Maagt, P.
GNSS-R Observations of Marine Plastic Litter in a Water Flume: An Experimental Study. *Remote Sens.* **2023**, *15*, 637. https://doi.org/10.3390/rs15030637

Conclusion

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- Observables which can be potentially used for marine litter detection:
  - Standard deviation of estimated reflectivity (or received signal power, or DDM peak).
    - Decreases sharply when there are waves, and increases a bit when capillary waves are present.
    - In general, it increases when there is marine litter.
  - Standard deviation of the phase (phase of peak of DDM, if no incoherent averaging) can also be used.
  - Kurtosis and Skewness (in some cases).
- Results extrapolation to airborne and spaceborne cases is not straightforward:
  - Different surface roughness in vortices (regardless of the presence -or not- of plastics)
  - Confirming the presence of biofouling and increased wave damping
  - Increased integration times from spaceborne sensors

Thank you for your attention!

amadeu.gonga@upc.edu
adrian.perez.portero@upc.edu
adriano.jose.camps@upc.edu