WELCOME

United States Contributions to Global Ocean Plastic Waste Meeting 3

For Zoom participants, send questions in Q&A feature.

Committee Members

Margaret Spring, Chair, *Monterey Bay Aquarium*
Mary Donohue, *University of Hawai'i*
Michelle Gierach, *NASA Jet Propulsion Laboratory*
Jenna Jambeck, *University of Georgia*
Hauke Kite-Powell, *Woods Hole Oceanographic Institution*
Kara Lavender Law, *Sea Education Association*
Jay Lund, *University of California Davis*
Ramani Narayan, *Michigan State University*
Eben Schwartz, *California Coastal Commission*
Rashid Sumaila, *University of British Columbia*

Committee Statement of Task

1.) Evaluate US contributions to global ocean plastic waste, including types, sources and geographic variations

2.) Assess the prevalence of marine debris and mismanaged plastic waste in saltwater and freshwater United States waterways

3.) Examine the import and export of plastic waste to and from the United States, including the destinations of the exported plastic and the waste management infrastructure and environmental conditions of these locations.

Committee Statement of Task

4.) Assess the potential value of a national marine debris tracking and monitoring system and how such a system might be designed and implemented.

5.) Develop recommendations on knowledge gaps that warrant further scientific inquiry.

6.) Recommend potential means to reduce United States contributions to global ocean plastic waste.

Agenda

12:00 pm	**Welcome and overview of the day** – Margaret Spring, Committee Chair
12:15 pm	**Automated micro-(FT)IR analysis for microplastics** Sebastian Primpke, Alfred Wegener Institute
1:00 pm	**Advances in the remote sensing of floating plastics litter and debris** Shungu Garaba, Carl von Ossietzky Universität Oldenburg
1:45 pm	*30 minute break*
2:15 pm	**Plastic remote sensing: development of algorithms and sensors for marine plastics** Victor Martinez-Vicente, Plymouth Marine Lab
3:00 pm	**Advancements on satellite remote sensing of marine plastics** Ellen Ramirez, National Oceanic and Atmospheric Administration

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

Automated micro-(FT)IR analysis for microplastics

Sebastian Primpke

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1. Alfred-Wegener-Institut, Biologische Anstalt Helgoland, Kurpromenade 201, 27498 Helgoland

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HELMHOLTZ

What are microplastics?

- Microplastics (MP) range from sizes from 5 mm down to 1 µm.
- MP are either used in industrial and end consumer products in this size range (primary MP) or formed during breakdown of larger items (secondary MP).
- Defined for legislation[1] as a material consisting of solid polymer-containing particles (polymer content ≥ 1% w/w)

1. State of California, STATE WATER RESOURCES CONTROL BOARD RESOLUTION NO. 2020-0021

Why it is important to analyze MP?

- Mandatory for monitoring[2] of microplastics < 500 µm
- May contain additional chemicals like plasticizers
- Risk assessment needs particle numbers, particle shape and polymer type[3]

2. GESAMP. Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean 2019.
3. Kögel T, et al. Sci Total Environ. 2020;709:136050. doi:10.1016/j.scitotenv.2019.136050.

How can microplastics be analyzed?

FTIR spectroscopy

- Determines particle numbers
- Polymer type characterization via reference databases or other chemometric approaches
- Particles >10 µm can be measured in a rapid fashion.

Raman spectroscopy

- Determines particle numbers
- Polymer type characterization via reference databases or other chemometric approaches
- Particles <1 µm can be measured, but the analysis is time consuming

Thermoanalysis-GC/MS

- Particle mass
- Using specific degradation products of the materials for quantification using signal to mass calibrations

4. Primpke S, et al., Appl Spectrosc. 2020;74(9):1012-47. doi:10.1177/0003702820921465.

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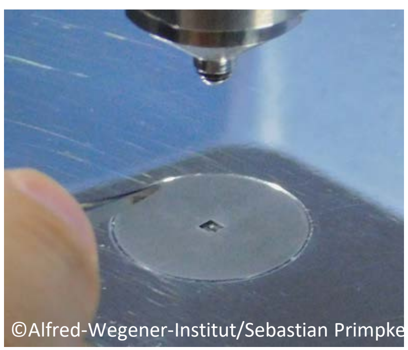
4. Primpke S, et al., Appl Spectrosc. 2020;74(9):1012-47. doi:10.1177/0003702820921465.

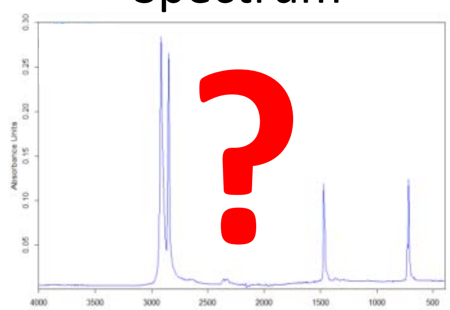
What is the benefit of infra red?

- Available by different instruments in the range of 5 mm to 10 µm.
- Measures the absorption of IR light by the various vibrational stages of the chemical bonds as a chemical fingerprint
- Chemical imaging possible via a non destructive method.

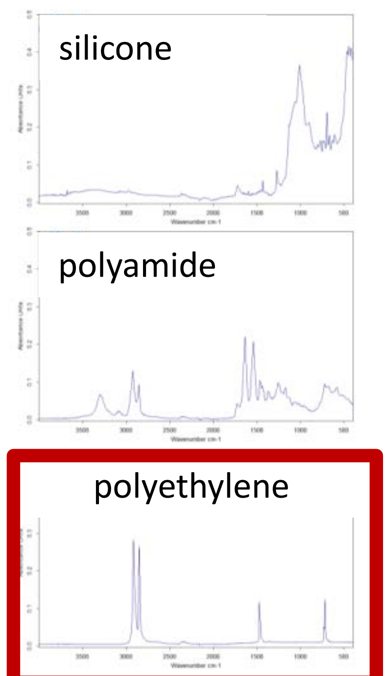


Infrared light

Spectrum



Library search



Chemical imaging

Independent from particle density on the filter

Allows the analysis of large filters (diameter usually 10 - 13 mm)

Applicable in transmission and reflection mode

Problem: Sample overload hampers analysis.

Example: Sediment sample

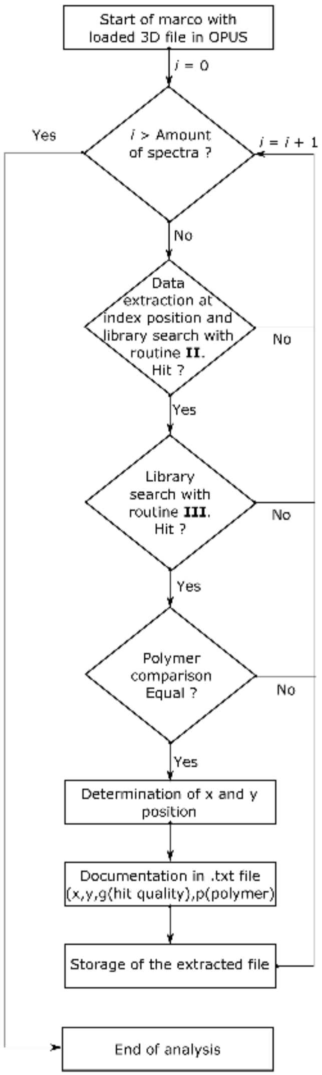
Automated Analysis

Combination of two library searches with different data handling

- ➢ Correlation of the original spectrum with vector normalization
- ➢ Correlation with the 1st derivative of the original spectrum with vector normalization

Successfully automated data generation with a 3% error value

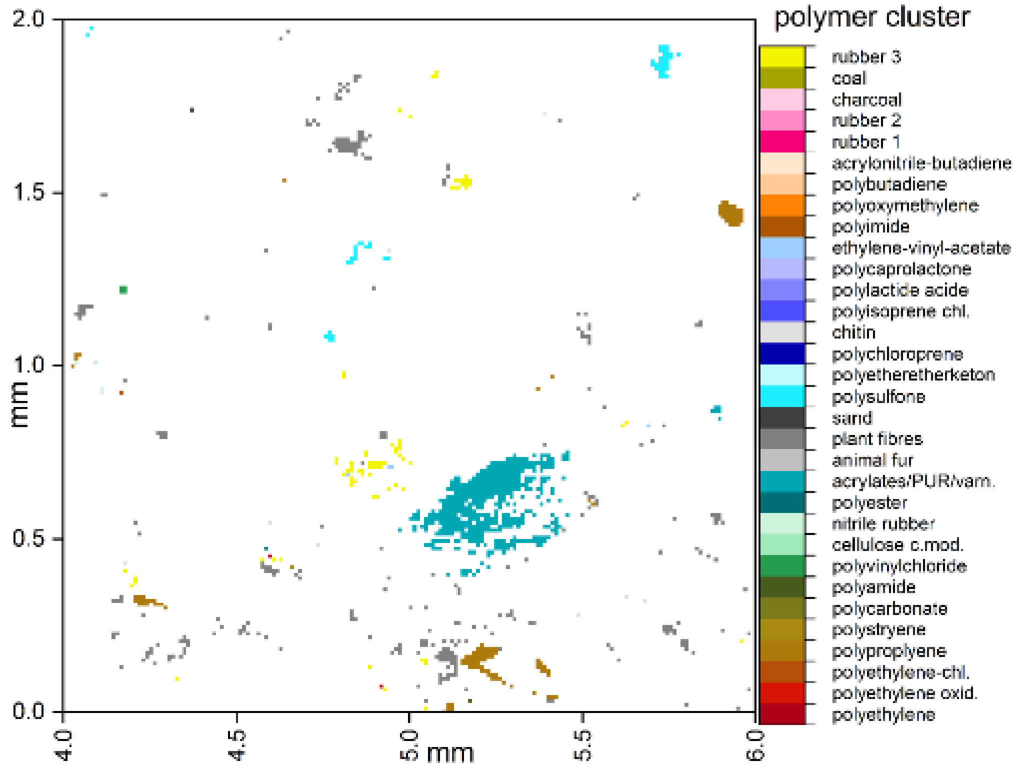
Transformation into images possible



Graph: CC 4.0-BY-NC, Primpke et. al., *Anal. Methods*, 2017, *9,* 1499–1511

Image Analysis

Implementation of an analytical program based on Python and SimpleITK



© Alfred-Wegener-Institut/ Sebastian Primpke

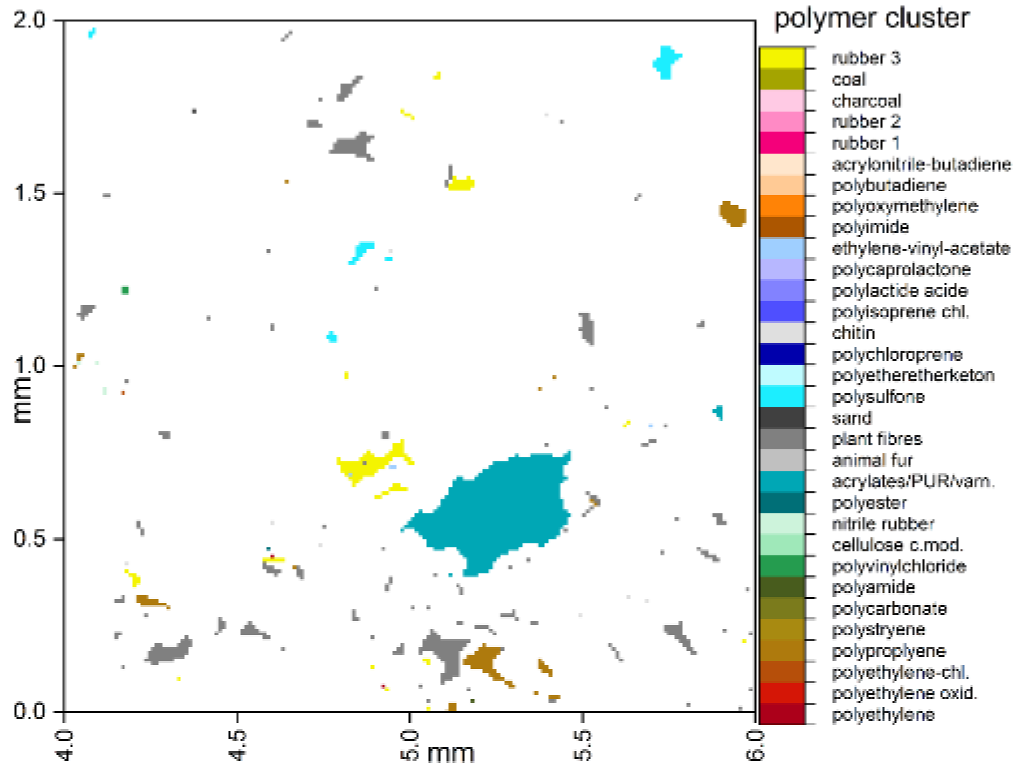
Primpke et. al., *Anal. Methods*, **2017**, *9*, 1499–1511

Image Analysis

Implementation of an analytical program based on Python and SimpleITK

Allows determination of particle sizes

Resulting in high quality data within a short time



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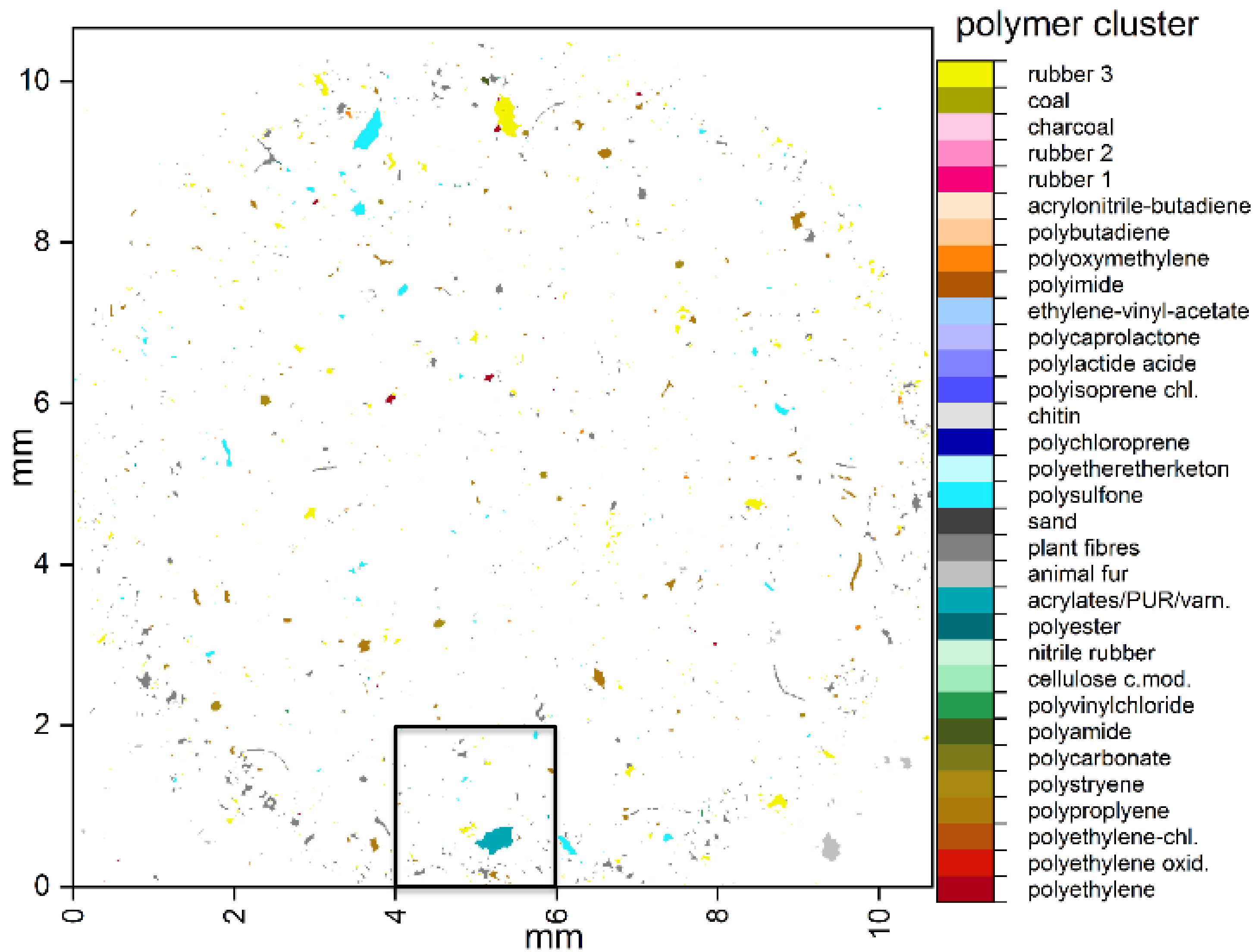
Primpke et. al., *Anal. Methods*, **2017**, *9,* 1499–1511

And on larger scale



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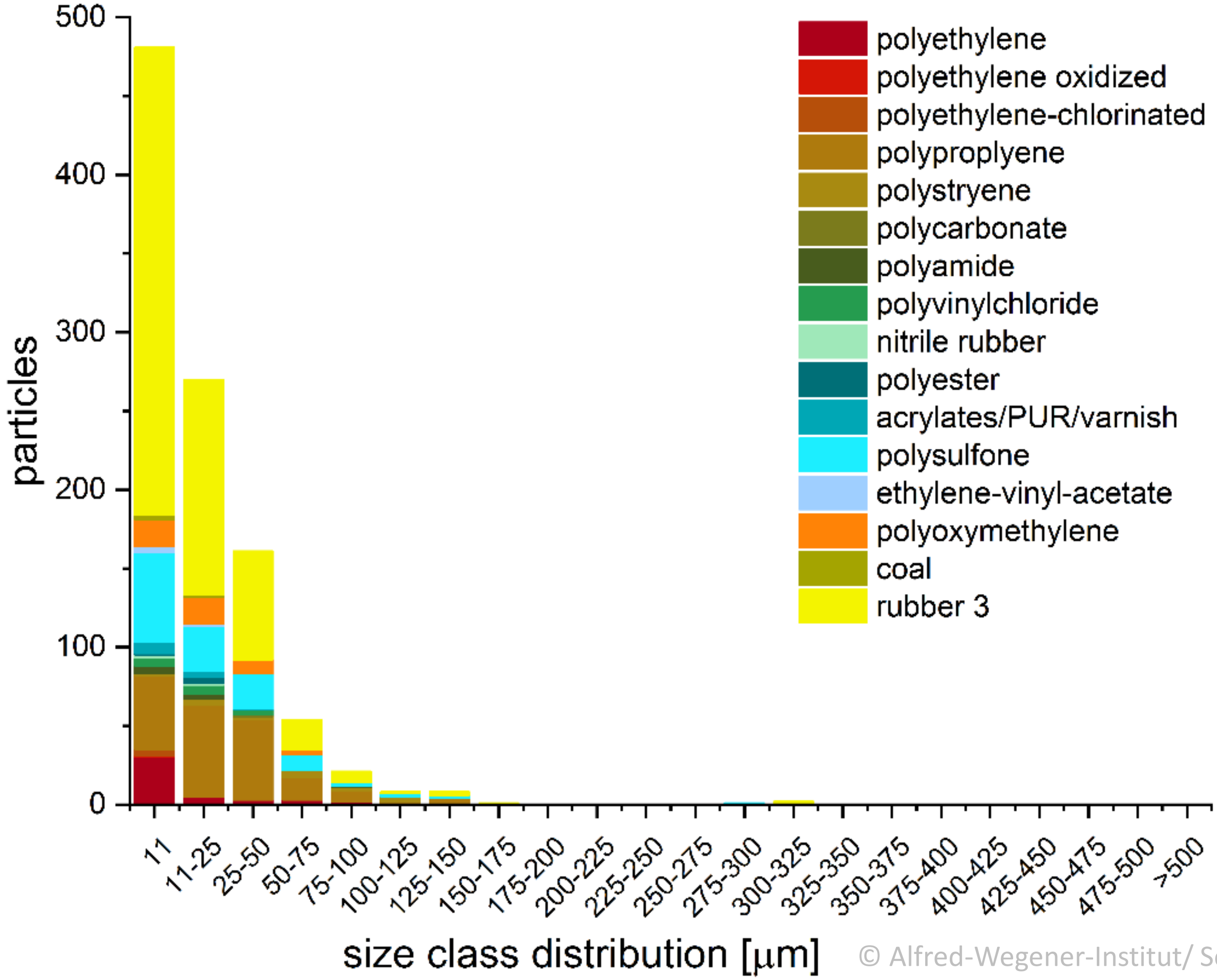
After Particle Analysis

Size distribution combined with determined polymer level:



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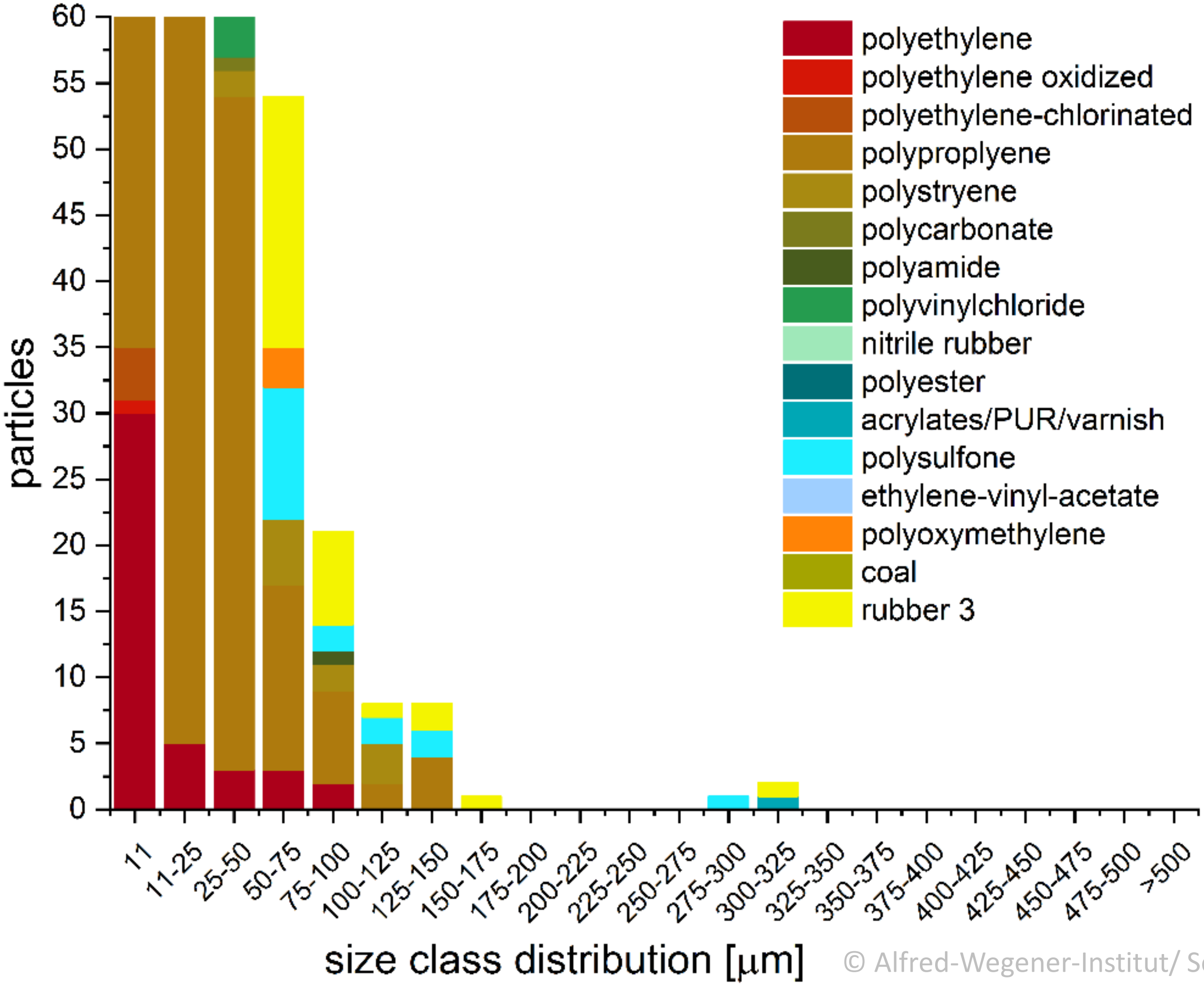
After Particle Analysis

And as zoom in:



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Harmonization by automated analysis

Automatization of microplastic analysis
based on FTIR imaging

- Data analysis independent from human bias via automated analysis
- Identification and Quantification of MP already within this process
- Time saving due to parallelization
- High comparability of results!

Harmonization!

Water samples (surface etc.)

Lorenz et al., 2019, EP
Tekman et al., 2020, ES&T
Mintenig et al., 2020, WR
Primpke et al. 2020, ABC

Treated waste water

Primpke et al., 2017, CHIUZ
Primpke et al., 2019, Analytical Methods
Mintenig et al., 2020, WR
Primpke et al. 2020, ABC

siMPle

Primpke et al., 2020, Applied Spectroscopy

Automatization of microplastic analysis based on FTIR imaging

Sediments

Bergmann et al., 2017, ES&T
Haave et al., 2019, MBP
Lorenz et al., 2019, EP
Mani et al., 2019, ES&T
Abel et al. 2019, EP
Primpke et al. 2020, ABC

Biota

In progress

(Arctic) Sea Ice

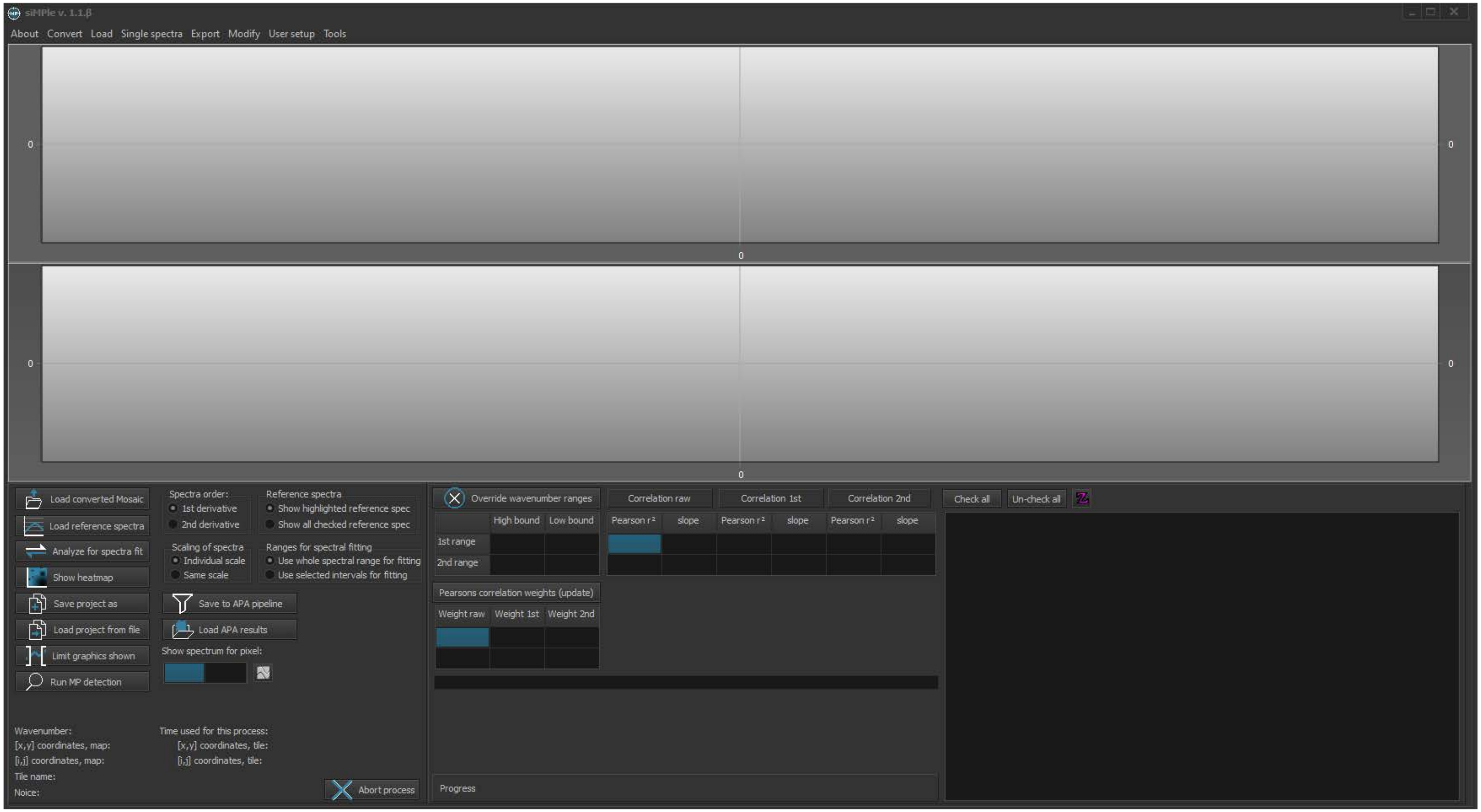
Peeken et al., 2018, Nature Communications

Snow

Bergmann et al., 2019, Science Advances

Automatization via siMPle

- Systematic Identification of MicroPLastics in the Environment (siMPle)
- Software tool available by CC-BY-SA 4.0 on www.simple-plastics.eu.



See also: Primpke, S., *et al*. 2020 Appl. Spectrosc. 74(9), 1127-1138. doi: 10.1177/0003702820917760

siMPle for various IR systems

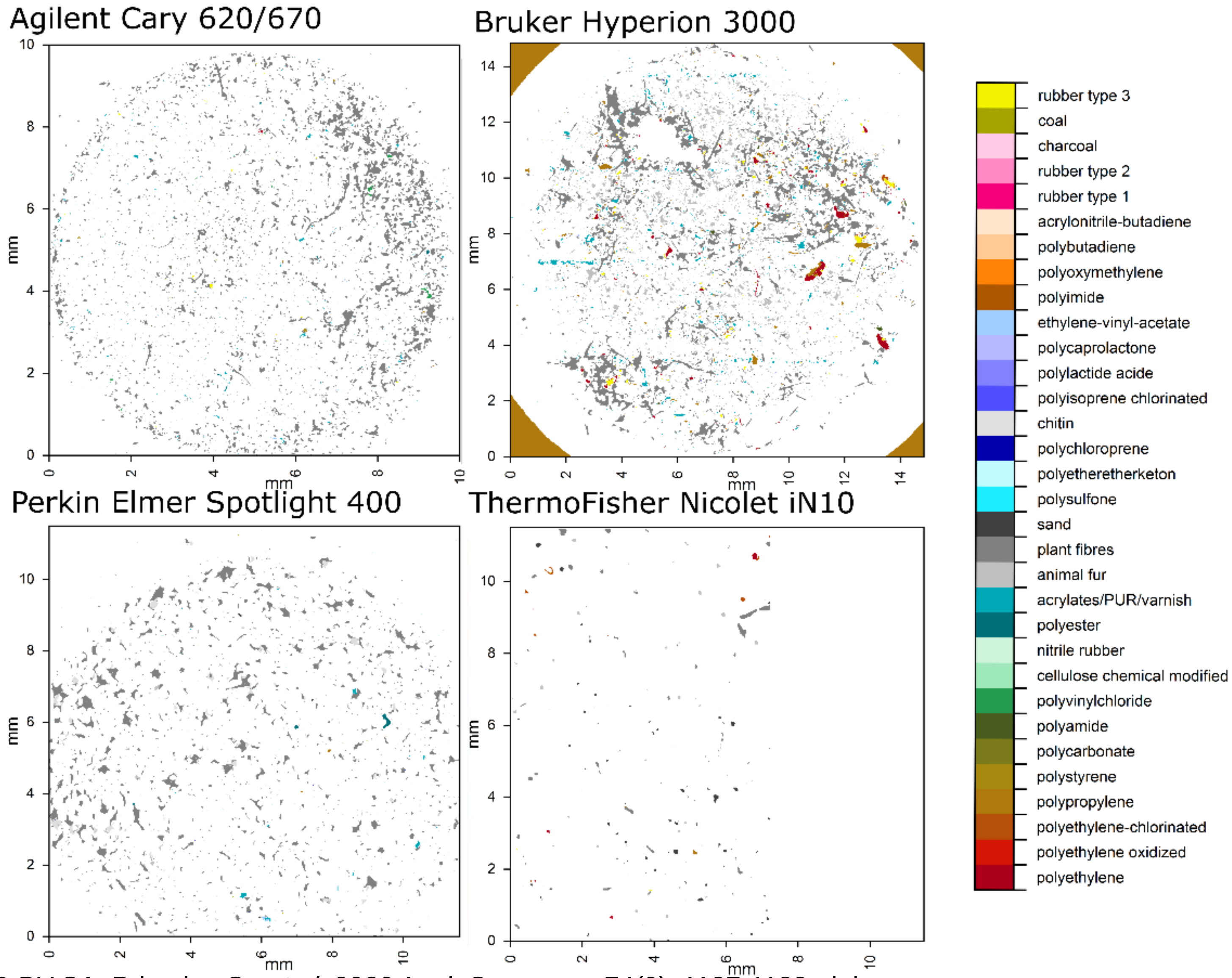
Universal application of data analysis using the same database.

- Not limited to one manufacturer
- Database is free of charge available
- Software is free of charge available
- Currently imports for Agilent, Bruker, DRS Daylight Solutions, Perkin Elmer and ThermoFischer Scientific

– Please contact us if you manufacturer is not in the list yet to find a solution

See also: Primpke, S., *et al*. 2020 Appl. Spectrosc. 74(9), 1127-1138. doi: 10.1177/0003702820917760

siMPle for various IR systems

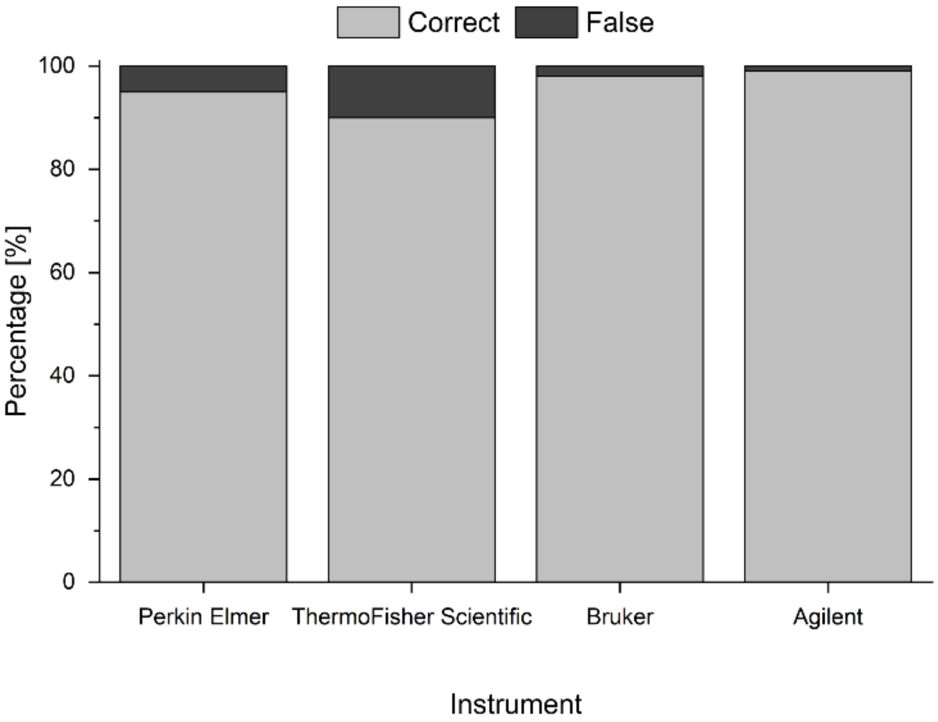


Graph: CC 4.0-BY-SA: Primpke, S., *et al.* 2020 Appl. Spectrosc. 74(9), 1127-1138. doi: 10.1177/0003702820917760

siMPle for various IR systems

Results of the intercomparsion

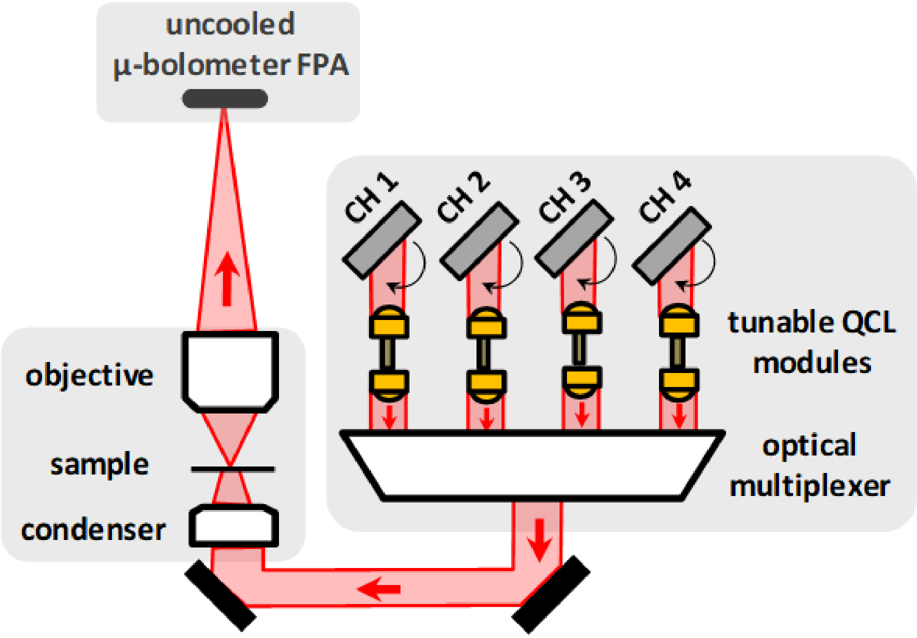
- All datasets yield identified particles
- Number of identified particles are dependent on the available pixel resolution
- All systems yielded mainly high ratios of correct assignments



Graph: CC 4.0-BY-SA: Primpke, S., *et al*. 2020 Appl. Spectrosc. 74(9), 1127-1138. doi: 10.1177/0003702820917760

Quantum Cascade Laser Imaging

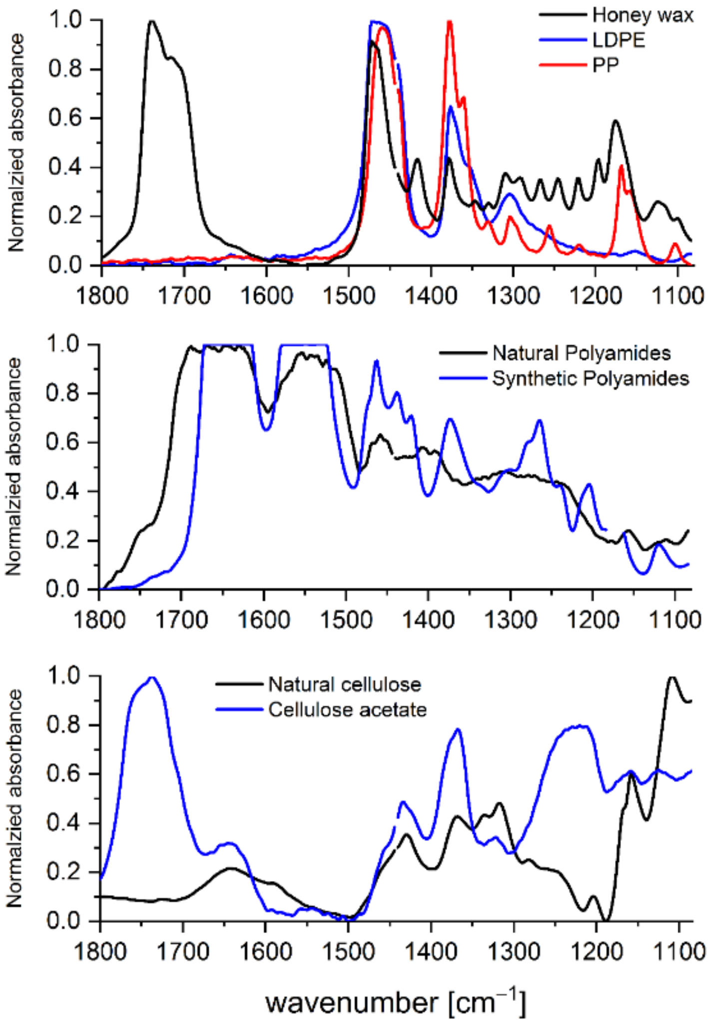
- DRS Daylight SperoQT: Setup similar to an infra red microscope
- Infra red source is a tunable laser
- No liquid nitrogen required
- Speed: 1 minute for a 2 × 2 mm field of view with a wavenumber range of 1800 – 950 cm^{-1}
- Resolution: 4.2 µm per pixel in the field of view



Graph: CC 4.0-BY Primpke S, et al. Environ Sci Technol. 2020;54(24):15893-903. doi:10.1021/acs.est.0c05722.

QCL based spectra on Anodisc

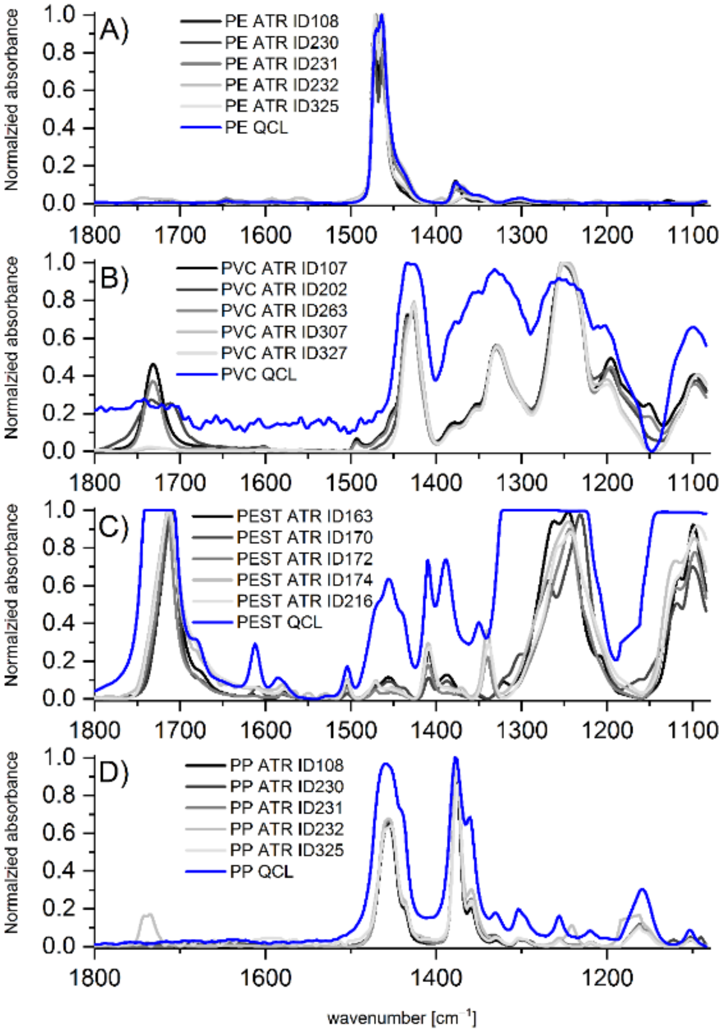
- Anodisc is one of the few suitable filters for IR
- Inexpensive, but limited in wavenumber range (>1250 cm^{-1})
- Using a QCL, measurements are possible until >1084 cm^{-1}
- Separation of natural and anthropogenic materials possible



Graph: CC 4.0-BY Primpke S, et al. Environ Sci Technol. 2020;54(24):15893-903. doi:10.1021/acs.est.0c05722.

QCL based spectra versus FTIR

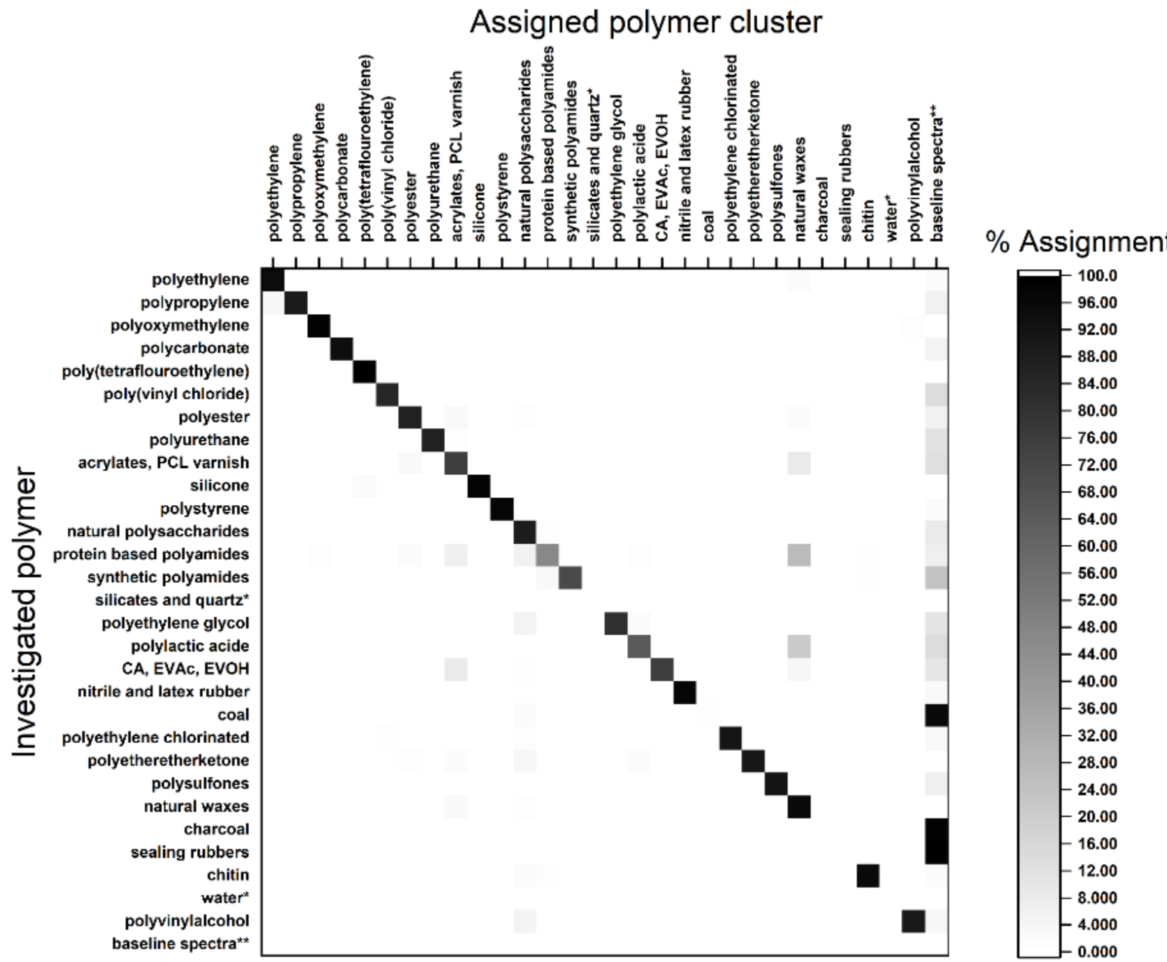
- Anodisc is one of the few suitable filters for IR
- Inexpensive, but limited in wavenumber range (>1250 cm^{-1})
- Using a QCL, measurements are possible until >1084 cm^{-1}
- Separation of natural and anthropogenic materials possible
- High similarity with ATR-FTIR spectra for most materials



Graph: CC 4.0-BY Primpke S, et al. Environ Sci Technol. 2020;54(24):15893-903. doi:10.1021/acs.est.0c05722.

Polymer types detectable

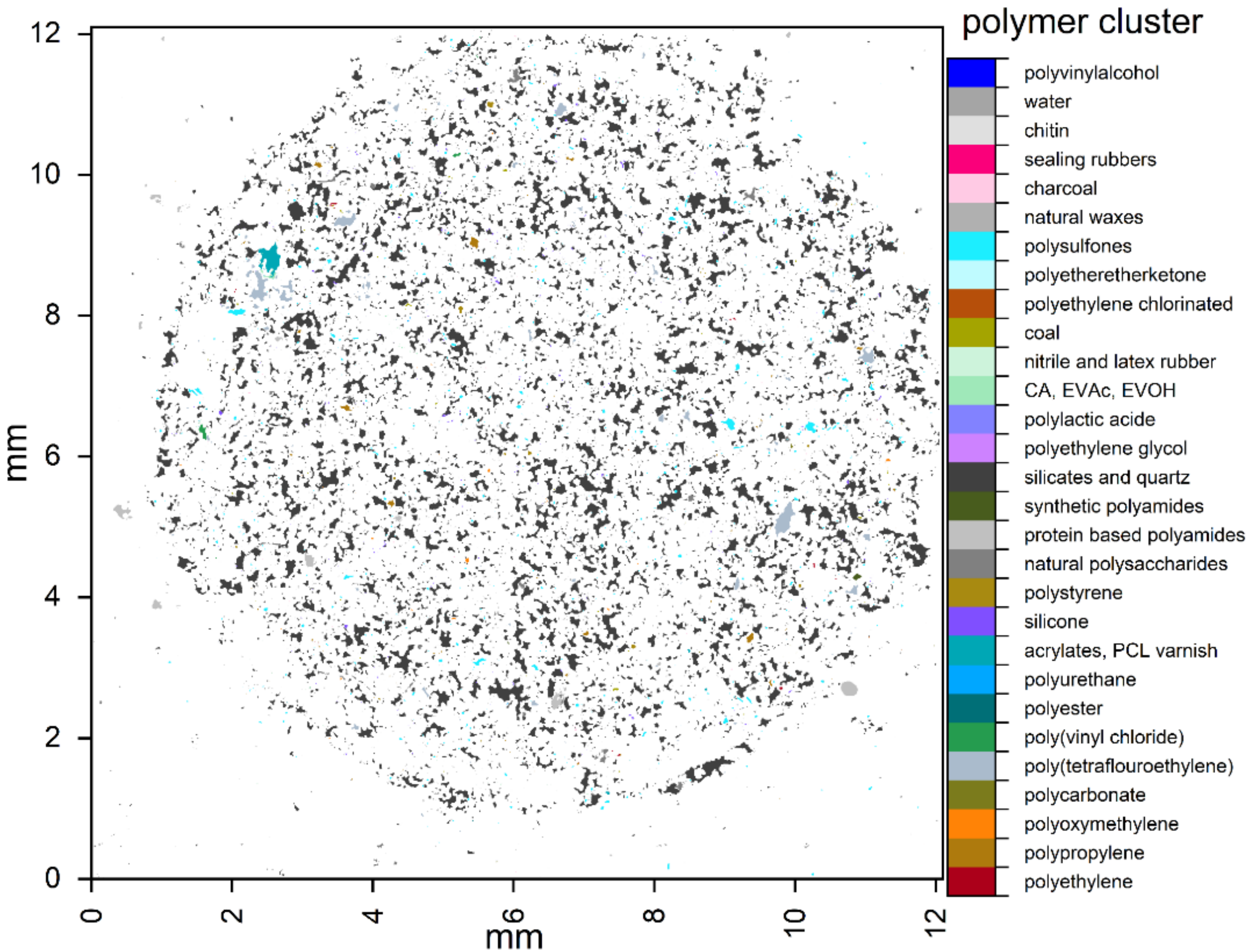
- Aiming for automated analysis
- Based on hierarchical cluster analysis
- Cluster generation based ATR-FTIR spectra
- Afterwards addition of QCL measured spectra



Graph: CC 4.0-BY Primpke S, et al. Environ Sci Technol. 2020;54(24):15893-903. doi:10.1021/acs.est.0c05722.

Results of the measurement

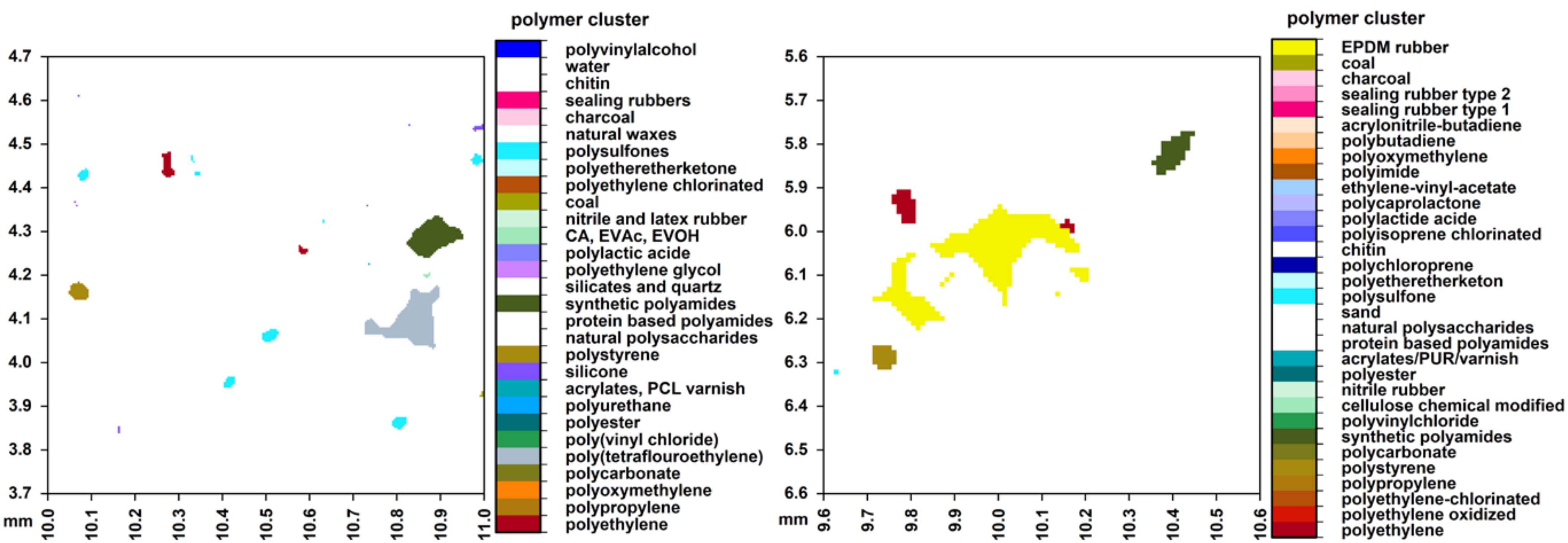
- Polymer dependent false color image from an exemplary sample



Graph: CC 4.0-BY Primpke S, et al. Environ Sci Technol. 2020;54(24):15893-903. doi:10.1021/acs.est.0c05722.

Comparsion with FTIR imaging

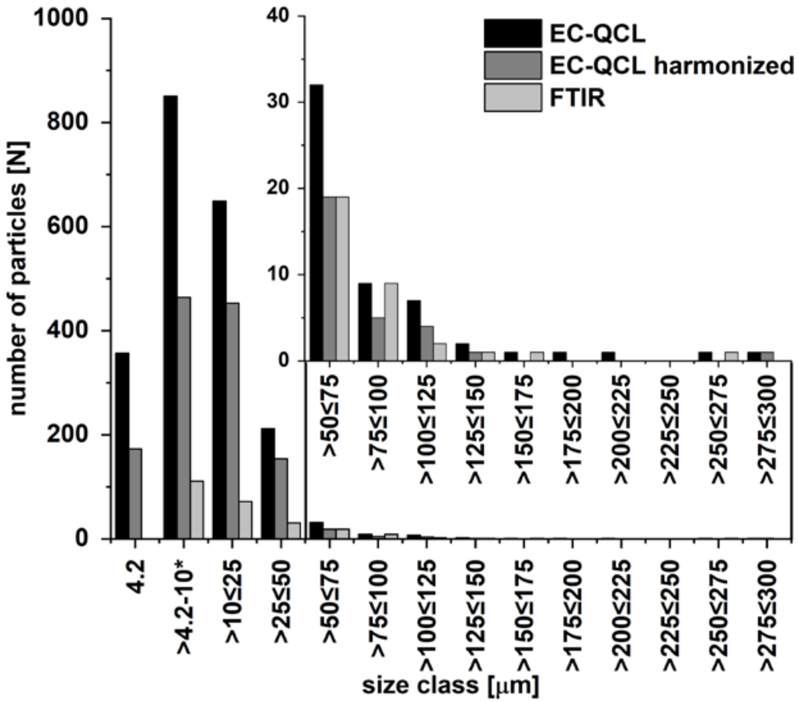
- ➢ Similar particles for main polymer types were found.
- ➢ In addition more polysulphones and also PTFE were detected.
- ➢ The large EPDM assigned particles were not detected.

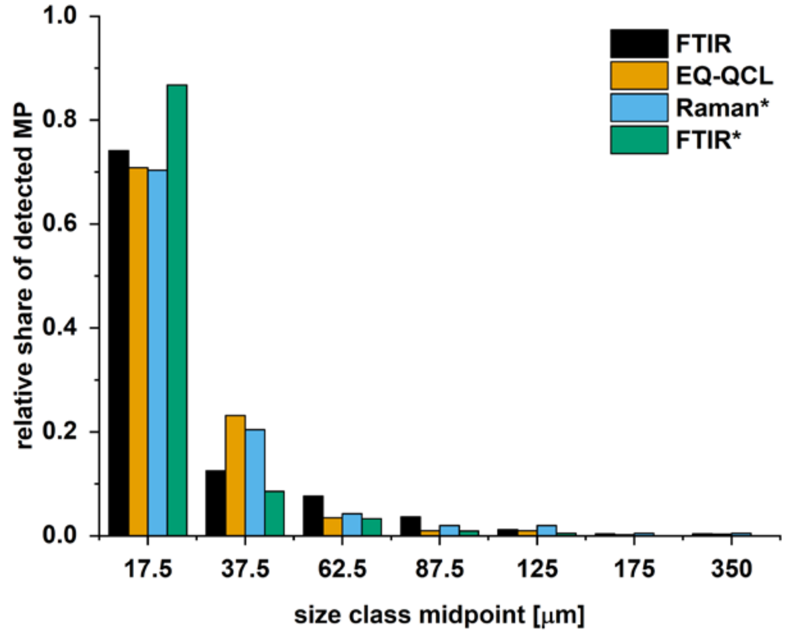


Graphs: CC 4.0-BY Primpke S, et al. Environ Sci Technol. 2020;54(24):15893-903.
doi:10.1021/acs.est.0c05722.

Comparsion with FTIR imaging

- ➢ More particles detected compared to FTIR imaging
- ➢ Similar relative particle shares like for Raman microscopy (Cabernard et al. 2018)





Graphs: CC 4.0-BY Primpke S, et al. Environ Sci Technol. 2020;54(24):15893-903. doi:10.1021/acs.est.0c05722.

Summary

Identification and quantification of microplastic by hyperspectral QCL imaging

- Low expenditure of time for measurement (36 minutes, 12 × 12 mm)
- Automated data analysis available
- Higher sensitivity for smaller particles compared to FTIR imaging
- Similar sensitivity for smaller particles compared to Raman
- Fast and reliable measurements

Conclusion

Automated micro-(FT)IR analysis for microplastics

- Low expenditure of time, fast and reliable analyses ✓
- Impartial analysis with a minimum of personnel requirements ✓
- Analytical methods and references applicable for various instruments and techniques ✓
- Quality Control is easily possible ✓

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Matthias Godejohann

www.mgopticalsolutions.com

DRS Daylight Solutions (Spero QT as a loan)

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MICROPLASTICS ANALYSES IN EUROPEAN WATERS

Carl von Ossietzky Universität Oldenburg

Advances in the remote sensing of floating plastic litter and debris

Invited Talk
NASEM United States Contributions to Global Ocean Plastic Waste

Dr. Shungu Garaba
shungu.garaba@uol.de

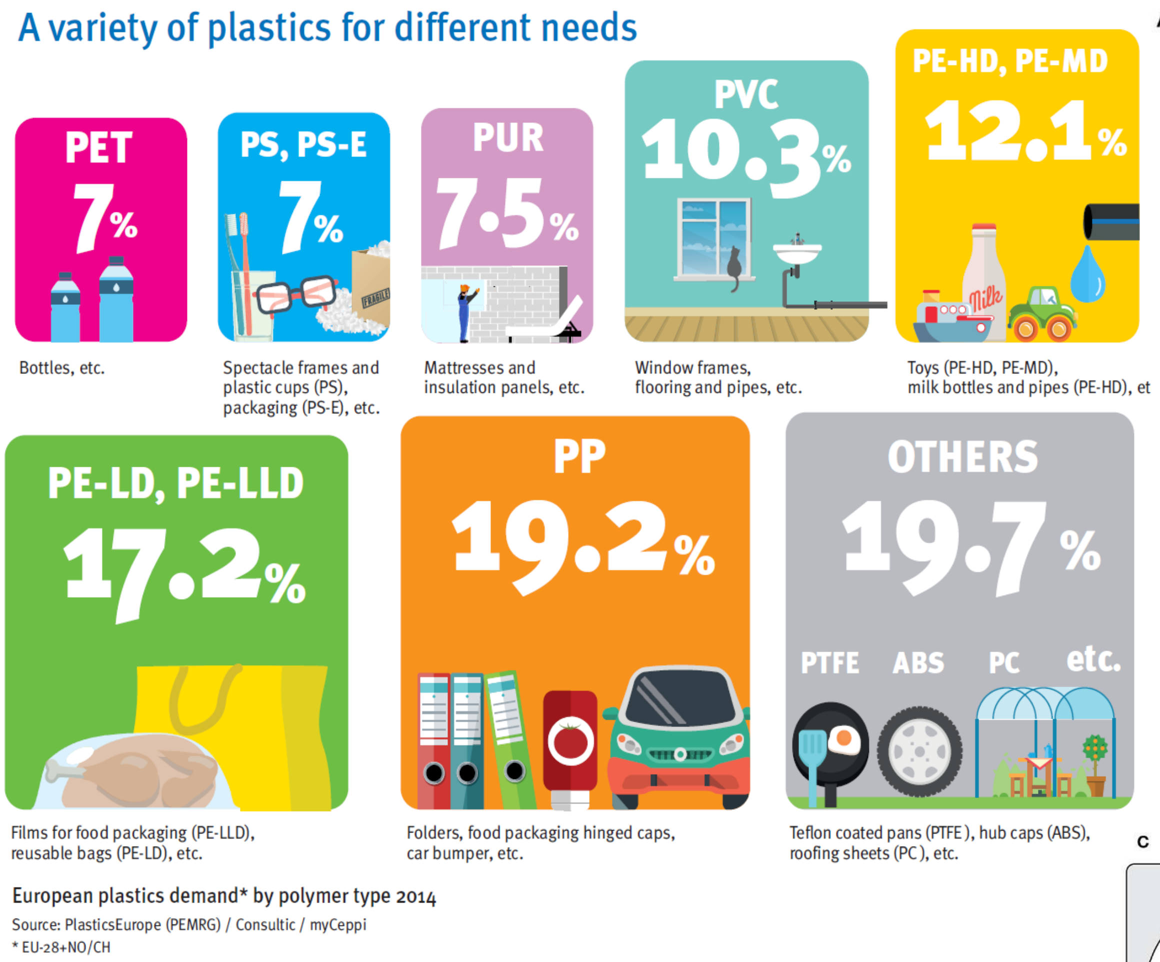
Carl von Ossietzky Universität Oldenburg

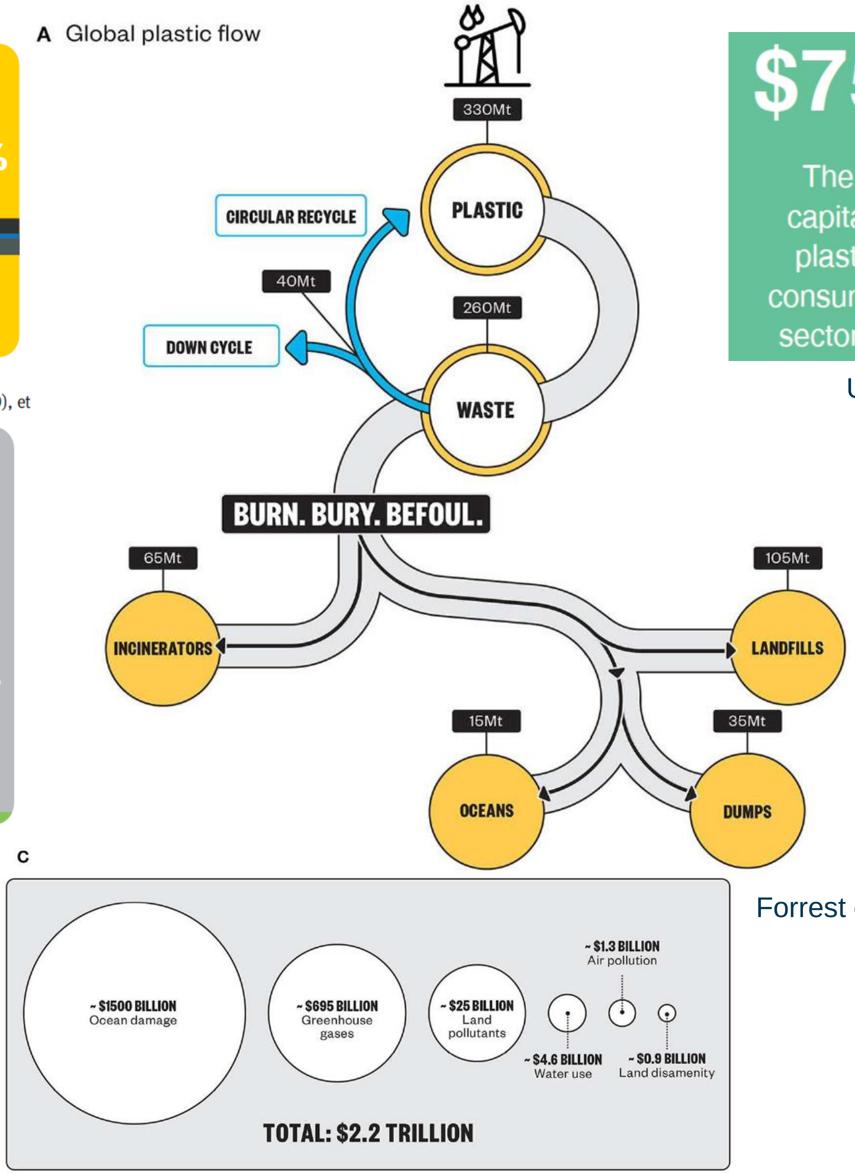
Talk Outline

- Introduction
  - ➢ Plastic Litter and Debris
  - ➢ Remote Sensing
- Objectives
- Milestones
  - ➢ Community Activities
  - ➢ Published Works
- Research Gaps

Introduction – Plastic Litter

- Plastics are part of our daily lives but **plastic litter** is considered an **expensive wicked environmental problem**.





Forrest et al., 2019

UNEP (2014)

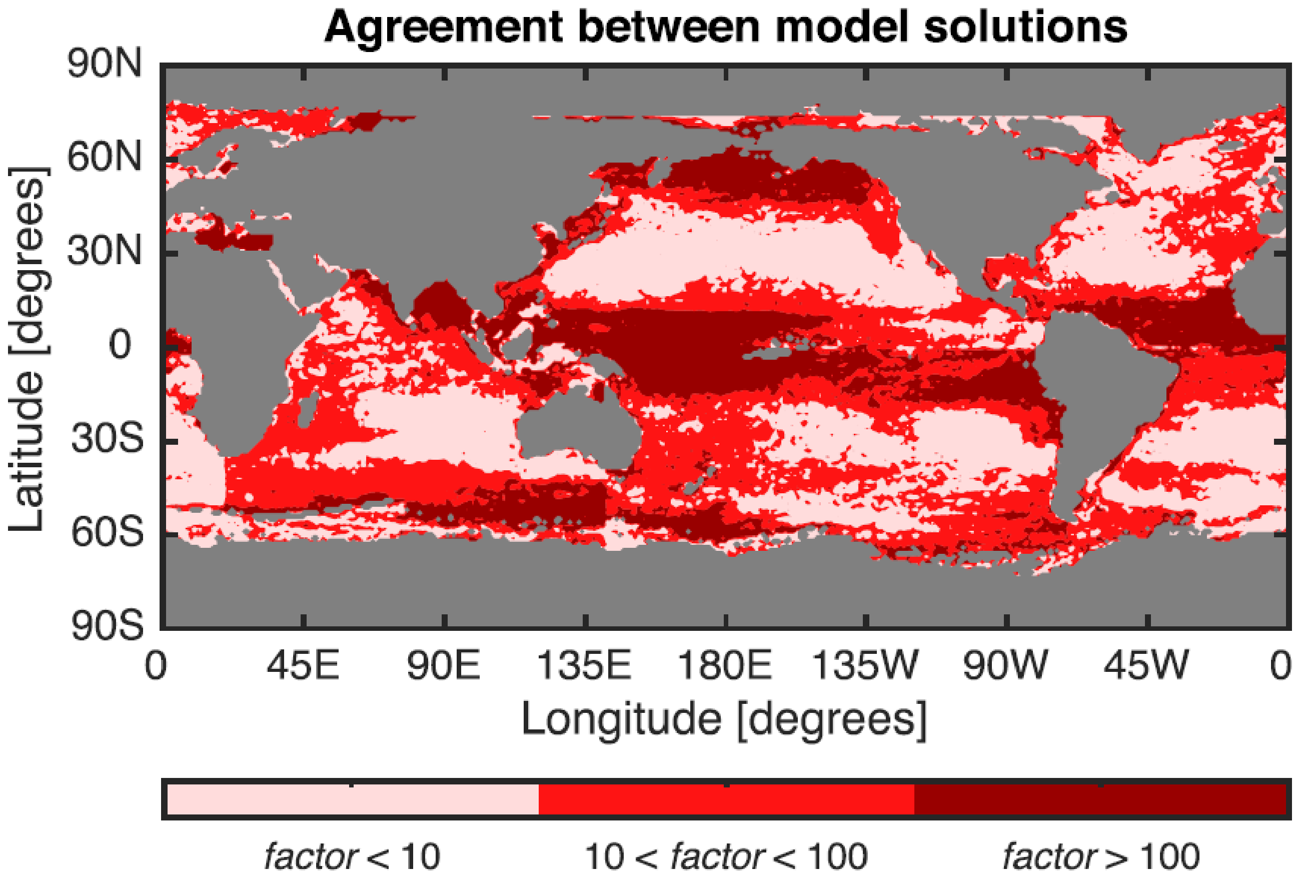
Introduction – Plastic Litter

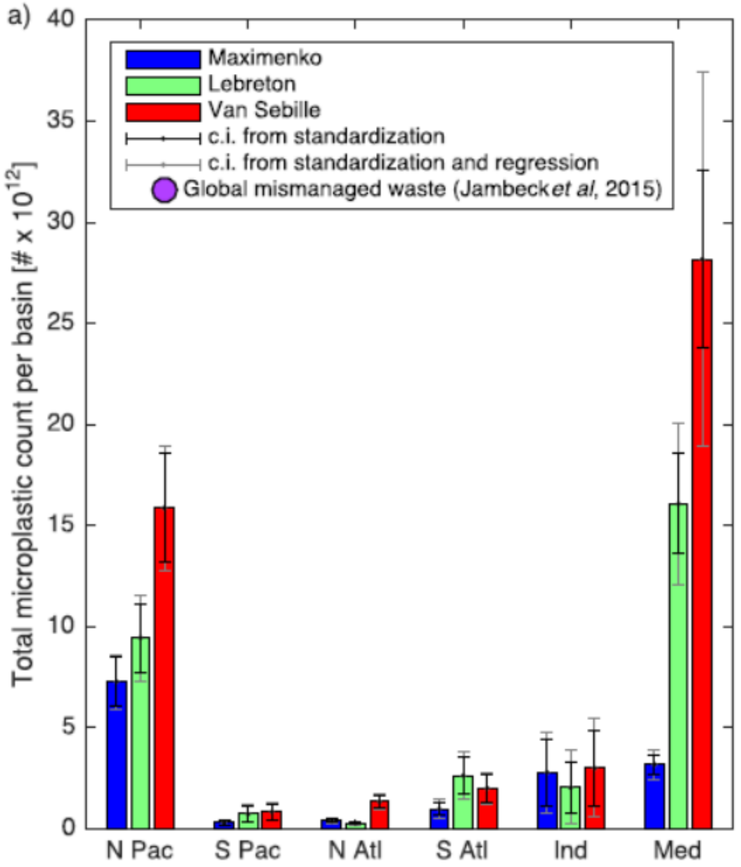
- Plastic materials have a long life span in the environment.

https://en.wikipedia.org/wiki/File:How_long_until_it%27s_gone.jpg

Introduction – Plastic Litter

- One of the challenges for stakeholders has been monitoring capabilities of available technologies.
- Numerical models of the plastics across the global oceans depends on **sparse data** restricted in **spatio-temporal** resolutions (van Sebille et al., 2015).
- A study on model estimates showed strong variabilities in the tropics and polar zones (van Sebille et al., 2015).



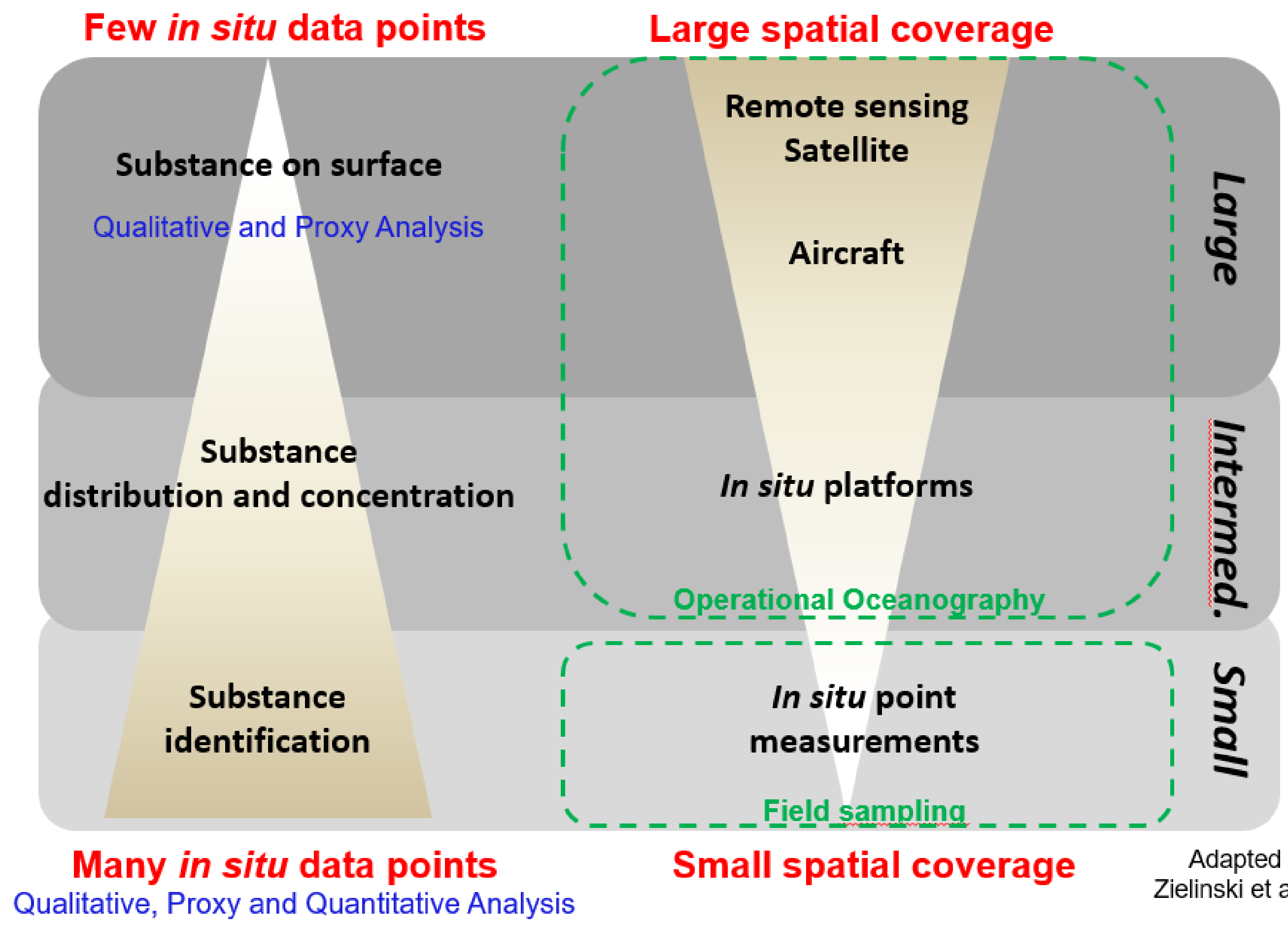


van Sebille et al., 2015

Introduction – Remote Sensing (Why?)

- It is a **non-invasive** way to study the ocean using light measured from a distant platform.

- The **geo-spatial**, **temporal** and **information depth/value** trade-offs complement in-situ monitoring strategies.



Adapted from
Zielinski et al., 2009

- Sensor technology applicable to ocean colour remote sensing is well established (IOCCG, 2008).

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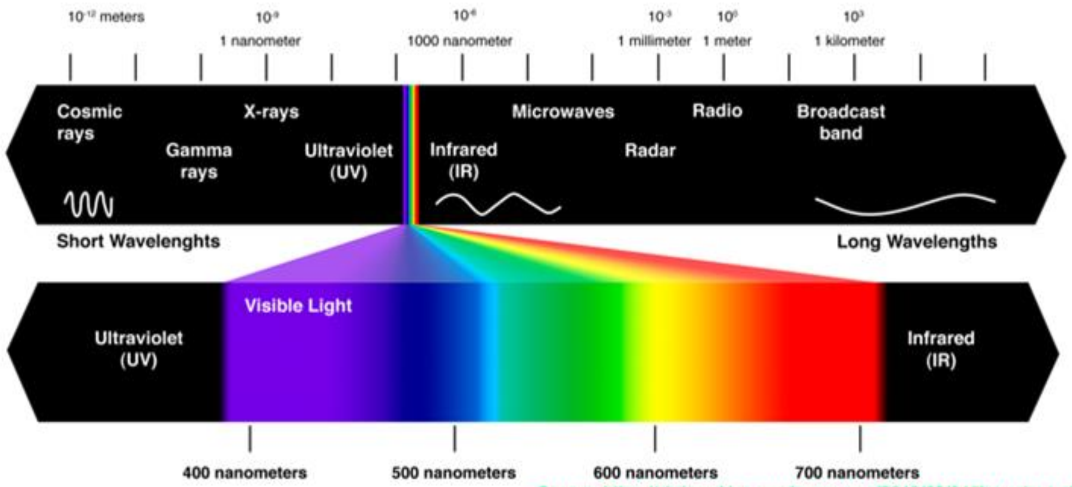
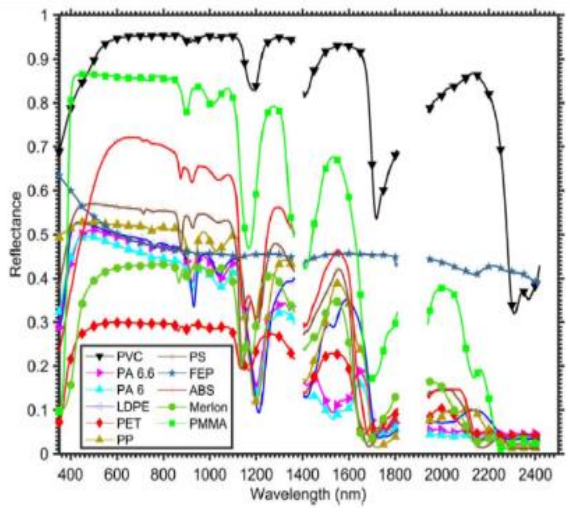
Introduction – Remote Sensing (How?)

- Plastics have unique optical signatures in the infrared (~750 - 2500 nm).

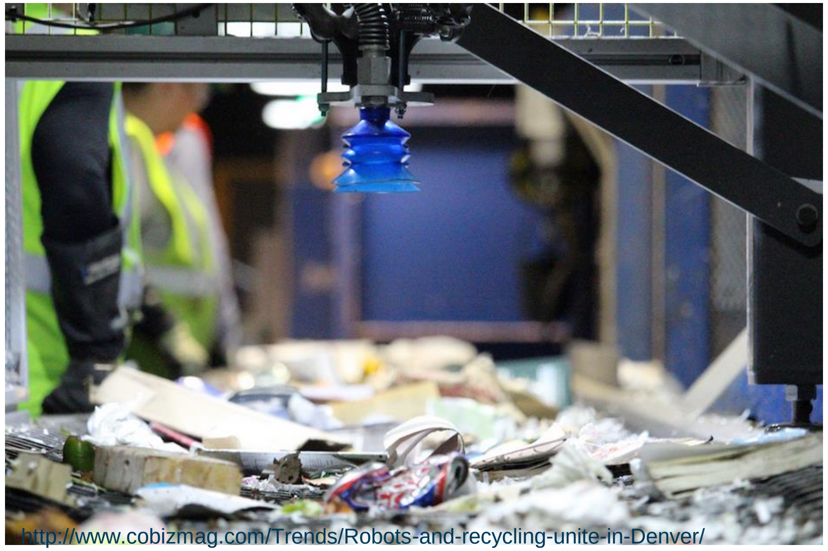


Source: https://chrisparkins.wordpress.com/2013/09/01/the-colour-of-light/



- These light properties have been utilized in automated sorting of plastics at recycling centres.

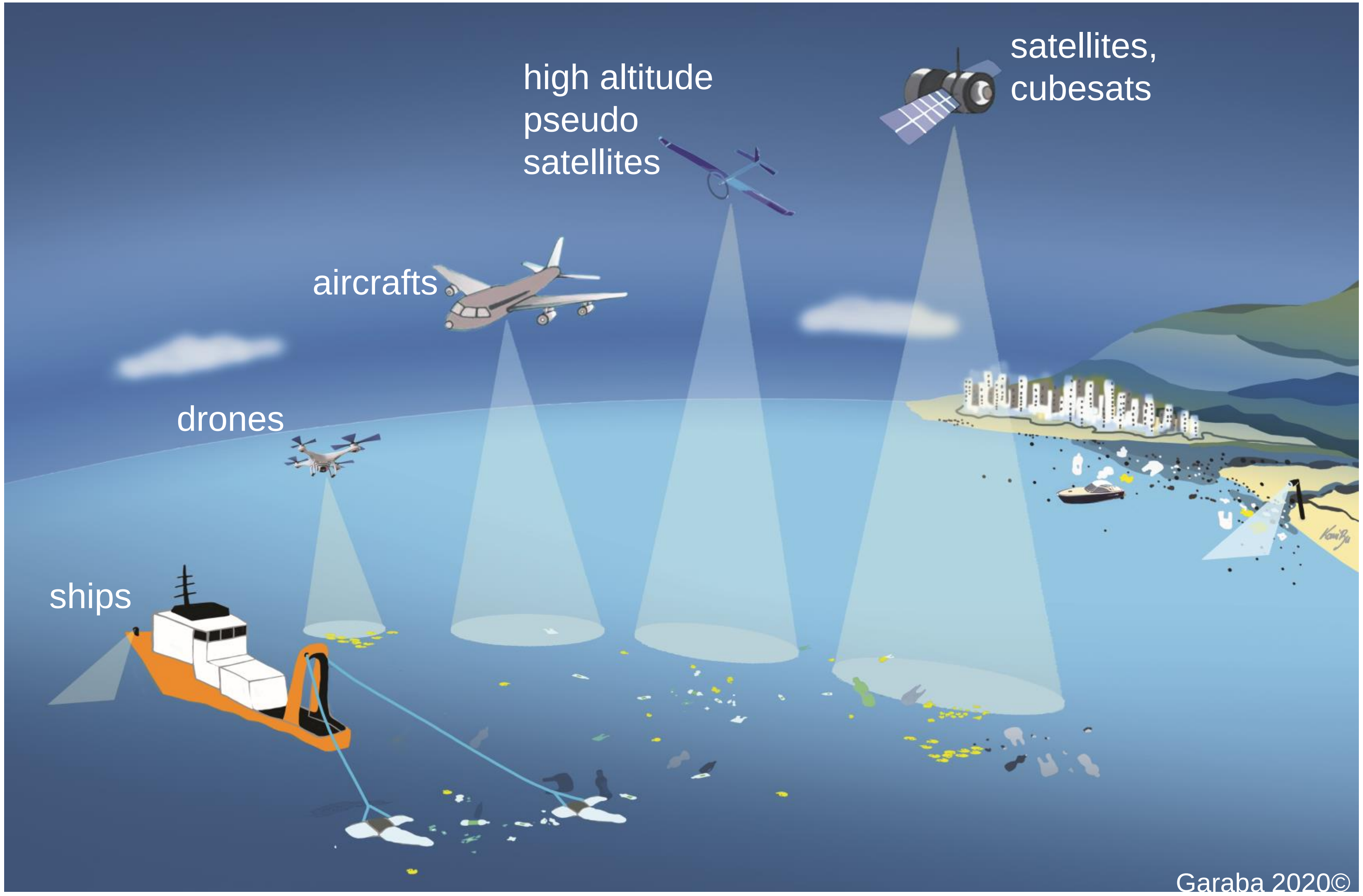
http://www.european-business.com/pellenc_st/portrait/



http://www.cobizmag.com/Trends/Robots-and-recycling-unite-in-Denver/

Objectives – Technologies

- Assess the prospects of **sustainable and innovative remote sensing technologies** as complementary sources of information about **aggregated** plastic litter.



Fixed observatories

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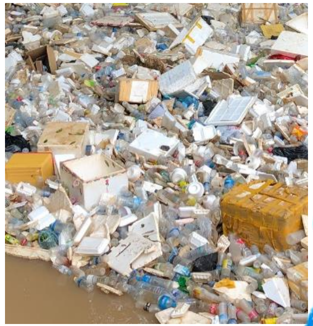
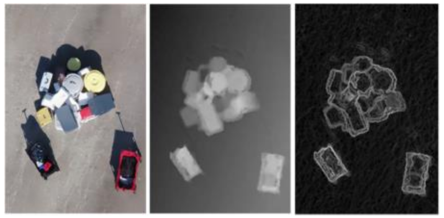
Objectives – Technologies

- These technologies have prospects in supporting **scientific evidence-based** approaches to **detect**, **identify**, **quantify** and **track** floating plastic litter.

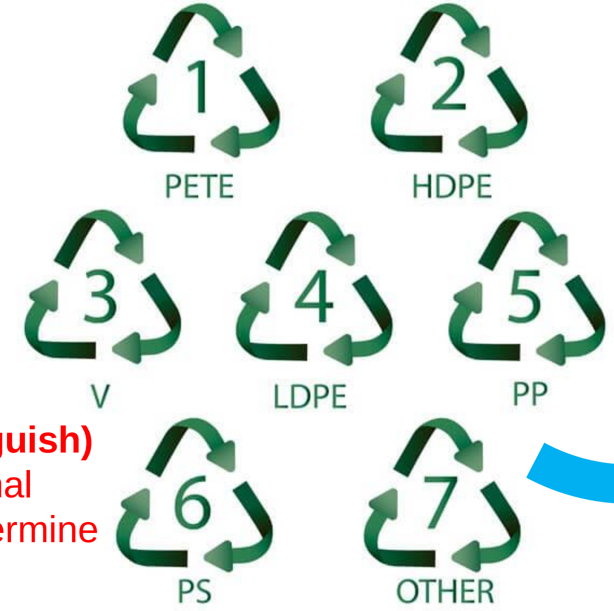



Track
Fixed platforms or geostationary, daily imagery utilizing the detection and identification algorithms.

Detect
Object identification algorithms using the shape, colour, size, form descriptors in RGB true colour images



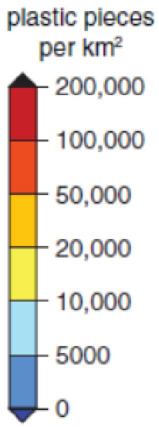
Kako et al., 2019



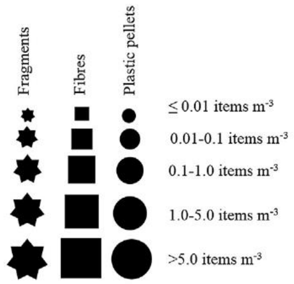
Identify (distinguish)
SWIR and thermal spectrum to determine polymers types.

https://www.acmeplastics.com/content/your-guide-to-plastic-recycling-symbols/

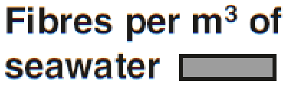
Quantify
Actual counts, pixel coverage, area coverage



Law et al., 2010



Ivar do Sul and Costa, 2014

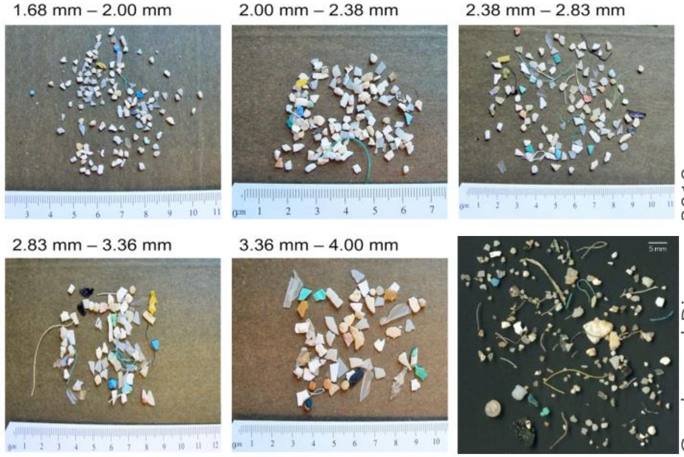


Bergmann et al., 2015

Objectives – Technological Limitations

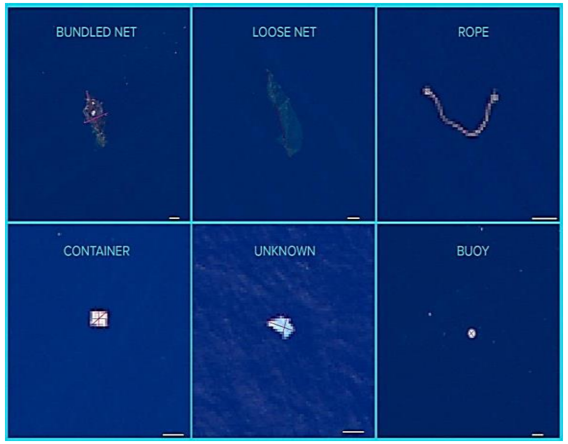
- Main constraint for remote sensing of plastic litter is the size continuum and diversity in composition.

- Current monitoring is restricted to large **aggregated** plastic patches with objects of varying size classes.



Garaba and Dierssen 2018
Jessica Donohue SEA Education

Microplastics

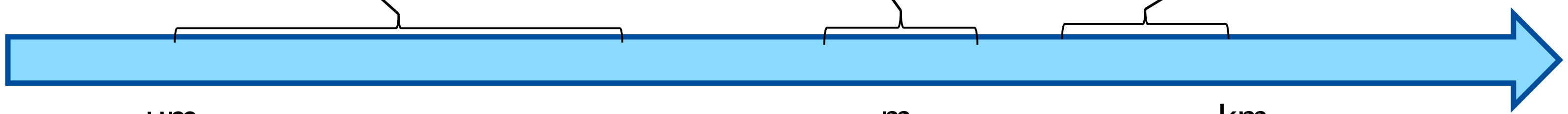


Lebreton et al., 2018

Large single debris
(e.g. ghost nets, ship ropes)

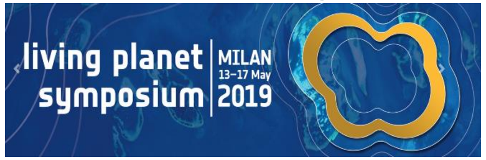
Caroline Power Photography

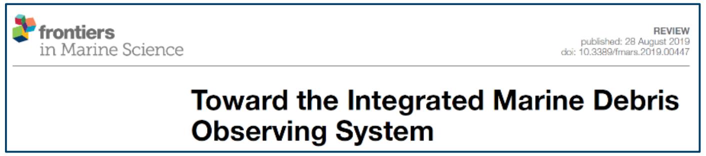
Large accumulations



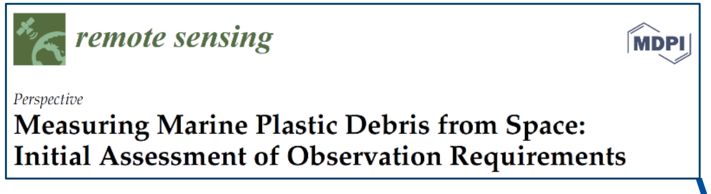
Size Matter

Milestones – Community Activities




frontiers in Marine Science
REVIEW
published: 28 August 2019
doi: 10.3389/fmars.2019.00447

Toward the Integrated Marine Debris Observing System


remote sensing
MDPI

Perspective
Measuring Marine Plastic Debris from Space: Initial Assessment of Observation Requirements

Portugal Space Agency

2020

ROSES project

Marine Plastics Research Group

ESA TEC (Discovery/OSIP),

EOP (EO4Society, Atlantic reg. init.),

TIA (Plastic-less society)

ESA Blue World Task Force

2019

2018

Working group SCOR – FLOTSAM Floating Litter and its Oceanic TranSport Analysis and Modelling).

2017

First ESA Workshop on Remote Sensing of Marine Litter

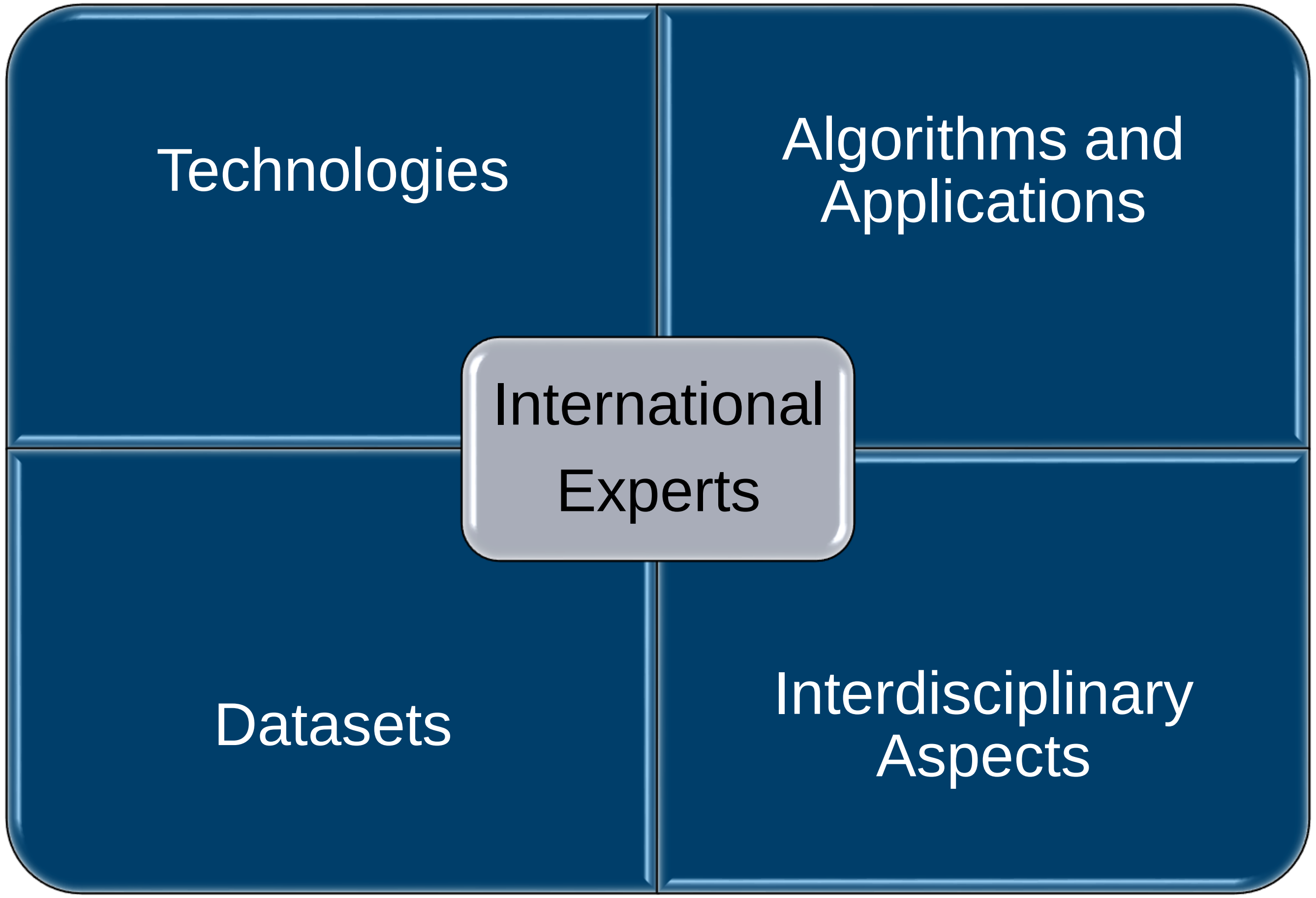
2016

Workshop on Mission Concepts for Marine Debris Sensing, University of Hawaii - Manoa

Carl von Ossietzky
Universität
Oldenburg

Milestones – Community Activities

- IOCCG Task Force on Remote Sensing of Marine Litter and Debris.
- Space agency representatives, experts in industry and academia.
- Core topics are expected to help create roadmap for stakeholders.



Carl von Ossietzky Universität Oldenburg

Published Works

Remote Sensing of Environment 205 (2018) 224–235

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

ELSEVIER

An airborne remote sensing case study of synthetic hydrocarbon detection using short wave infrared absorption features identified from marine-harvested macro- and microplastics

Shungudzemwoyo P. Garaba[a,*], Heidi M. Dierssen[a,b]

Environ. Res. Lett. 15 (2020) 114042 https://doi.org/10.1088/1748-9326/abbd01

Environmental Research Letters

LETTER

Machine learning for aquatic plastic litter detection, classification and quantification (APLASTIC-Q)

Mattis Wolf[1,2], Katelijn van den Berg[3], Shungudzemwoyo P Garaba[1,2], Nina Gnann[1], Klaus Sattler[3], Frederic Stahl[1,4] and Oliver Zielinski[1,2]

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Environmental Science & Technology

Article

Cite This: Environ. Sci. Technol. 2018, 52, 11699–11707 pubs.acs.org/est

Sensing Ocean Plastics with an Airborne Hyperspectral Shortwave Infrared Imager

Shungudzemwoyo P. Garaba,[*,†,‡,§] Jen Aitken,[†,∥] Boyan Slat,[†] Heidi M. Dierssen,[‡] Laurent Lebreton,[†,⊥] Oliver Zielinski,[§] and Julia Reisser[†,#,∇]

Journal of Hazardous Materials 406 (2021) 124290

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

ELSEVIER

Research paper

Concentration, anisotropic and apparent colour effects on optical reflectance properties of virgin and ocean-harvested plastics

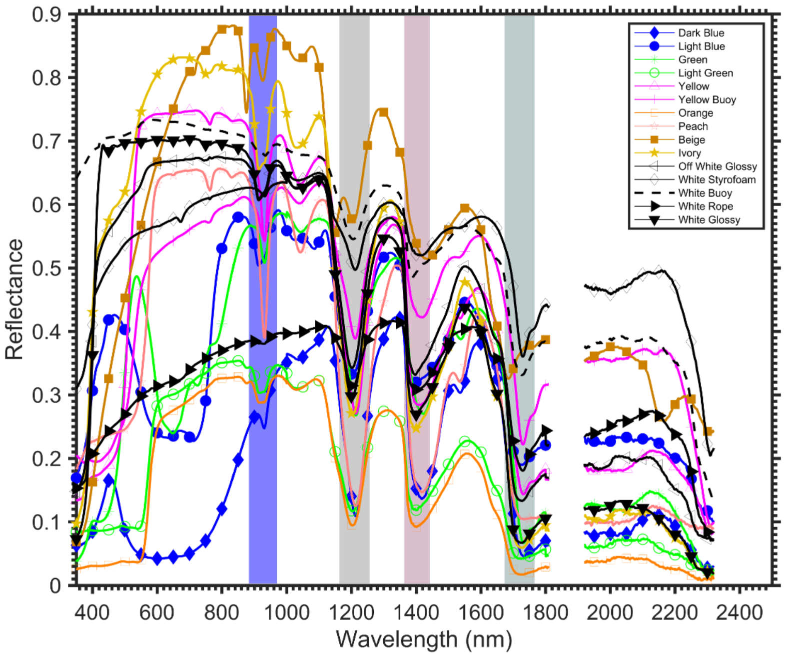
Shungudzemwoyo P. Garaba[a,b], Manuel Arias[c], Paolo Corradi[d], Tristan Harmel[e], Robin de Vries[a], Laurent Lebreton[a,f]

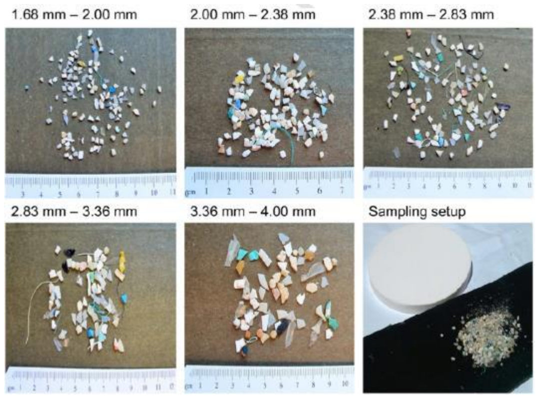
Carl von Ossietzky Universität Oldenburg

Published Works

- Aggregated microplastics (< 5 mm) were observed to share similar spectral shapes.

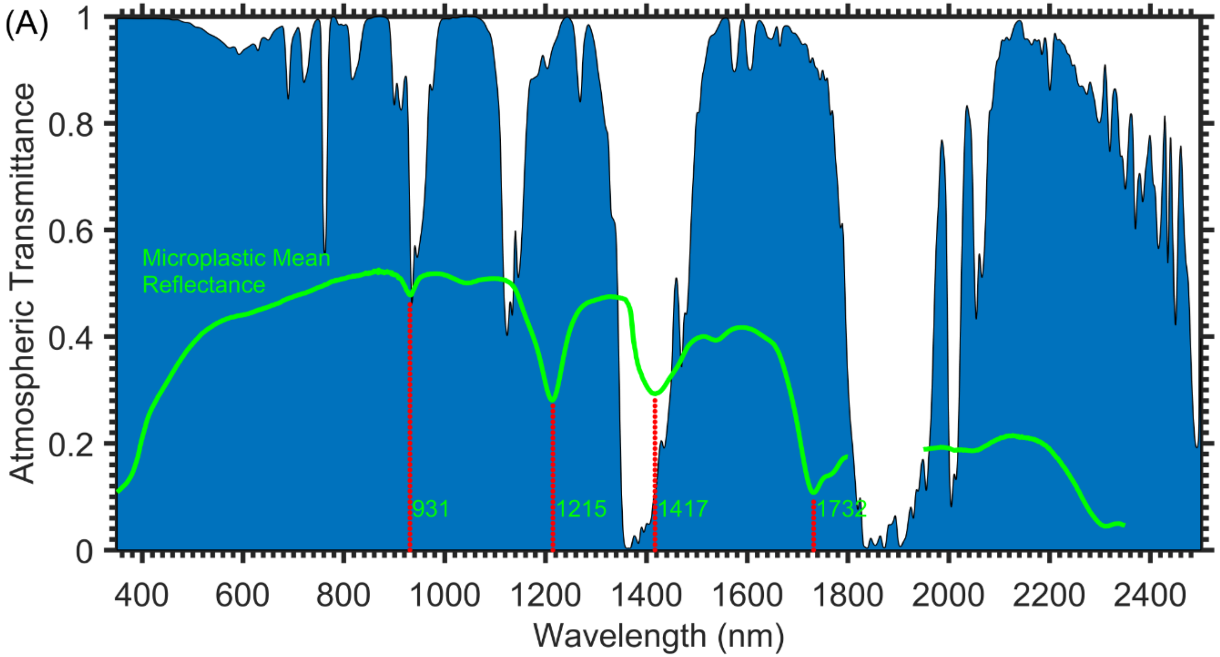
- Diagnostic absorption features of ocean-harvested and washed plastics were identified at **931**, **1215**, **1417** and **1732** nm.





Ocean harvested microplastics from the Kamilo Point Hawaii and North Atlantic Ocean.

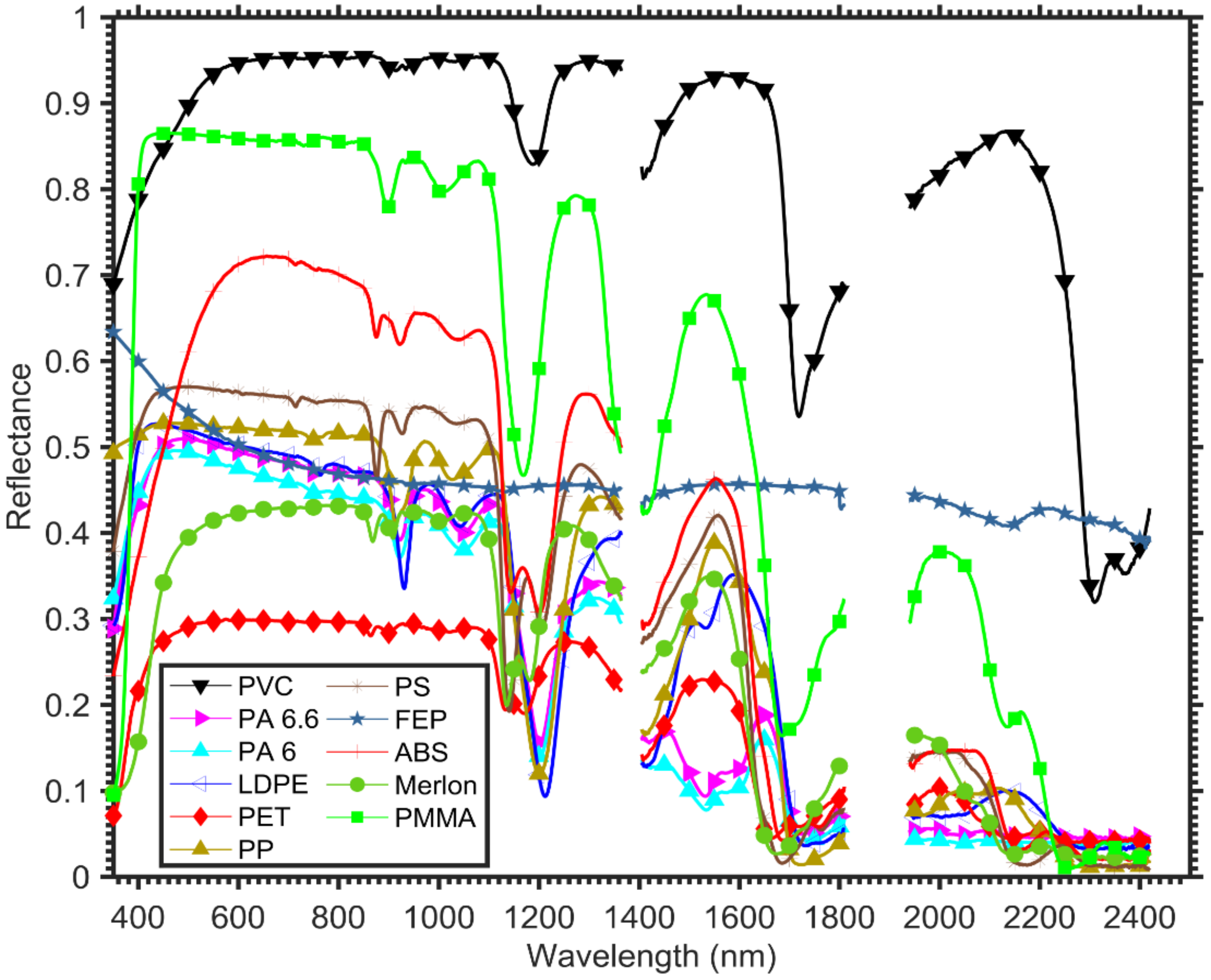
Washed ashore macroplastics (> 5mm) of different colours, shapes and size gathered from the west coast of USA.



Garaba and Dierssen 2018

Published Works

- An **open-access** spectral reference library was established to support polymer identification of ocean-harvested plastics.



- Polyvinyl chloride (PVC),
- Polyamide or nylon (PA 6.6 and PA 6),
- Low-density polyethylene (LDPE),
- Polyethylene terephthalate (PET),
- Polypropylene (PP),
- Polystyrene (PS)
- Fluorinated ethylene propylene teflon (FEP),
- Terpolymer lustran 752 (ABS),
- Merlon
- Polymethyl methacrylate (PMMA).

Garaba and Dierssen 2018

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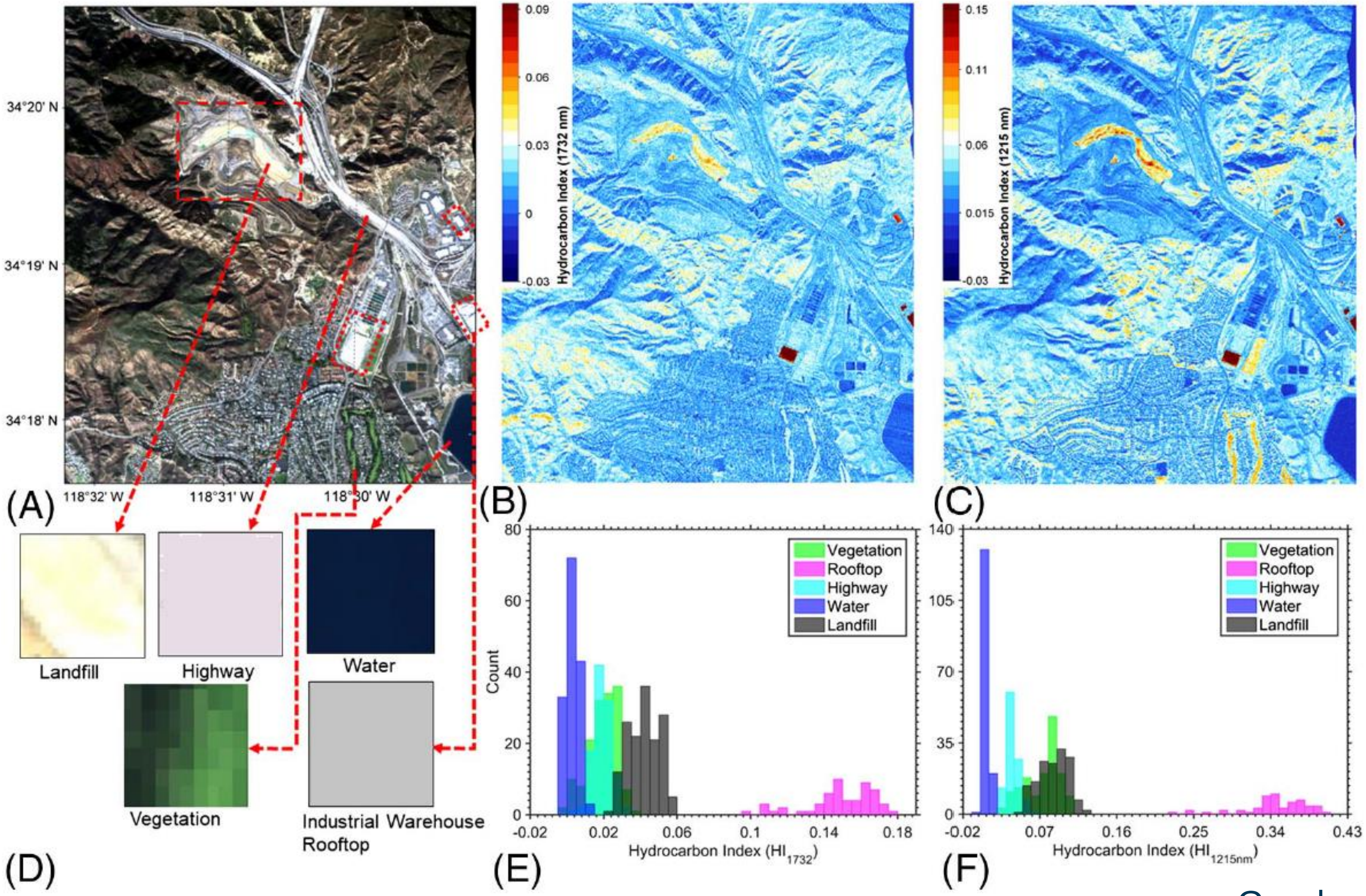
Published Works

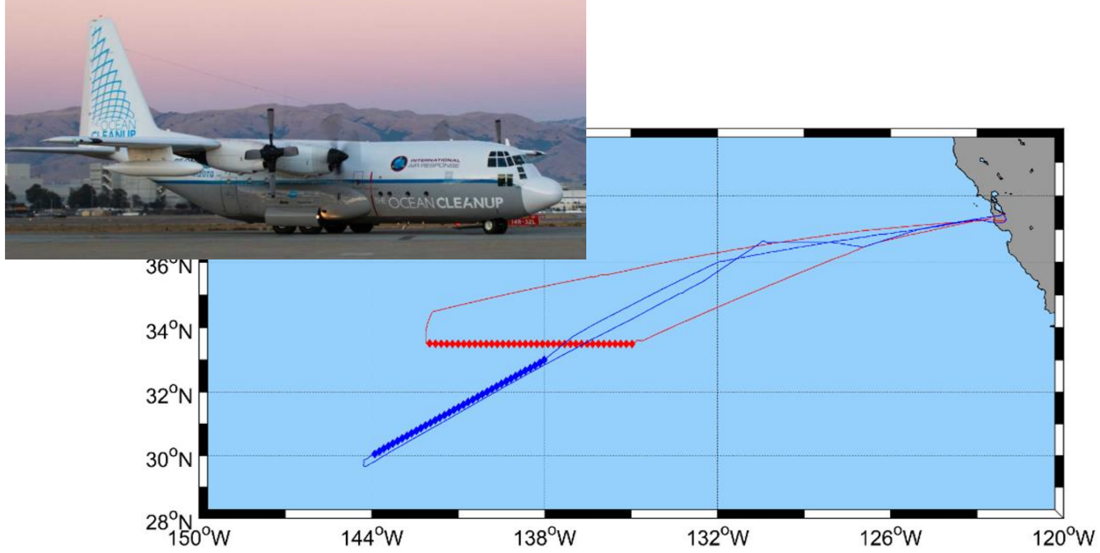
- Hyperspectral airborne imager (AVIRIS) was used to map and detect plastics over a landfill.
- Band depth algorithms were based on absorption features at 1215 and 1732 nm.

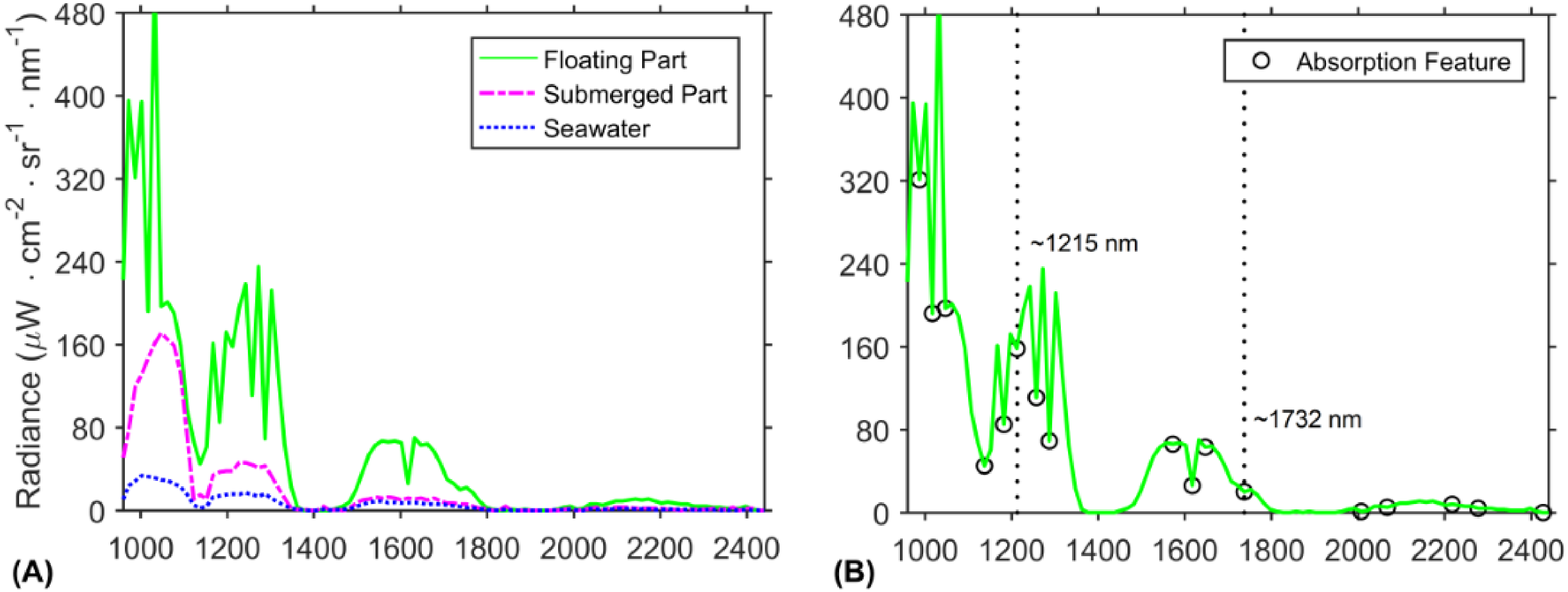


Garaba and Dierssen 2018

Published Works

- Detection of floating and slightly submerged macroplastics was demonstrated over the Great Pacific Garbage Patch from an aircraft.





Absorption features at 1215 and 1732 nm confirmed to be useful in detecting plastics with no need to apply atmospheric correction.

Garaba et al., 2018

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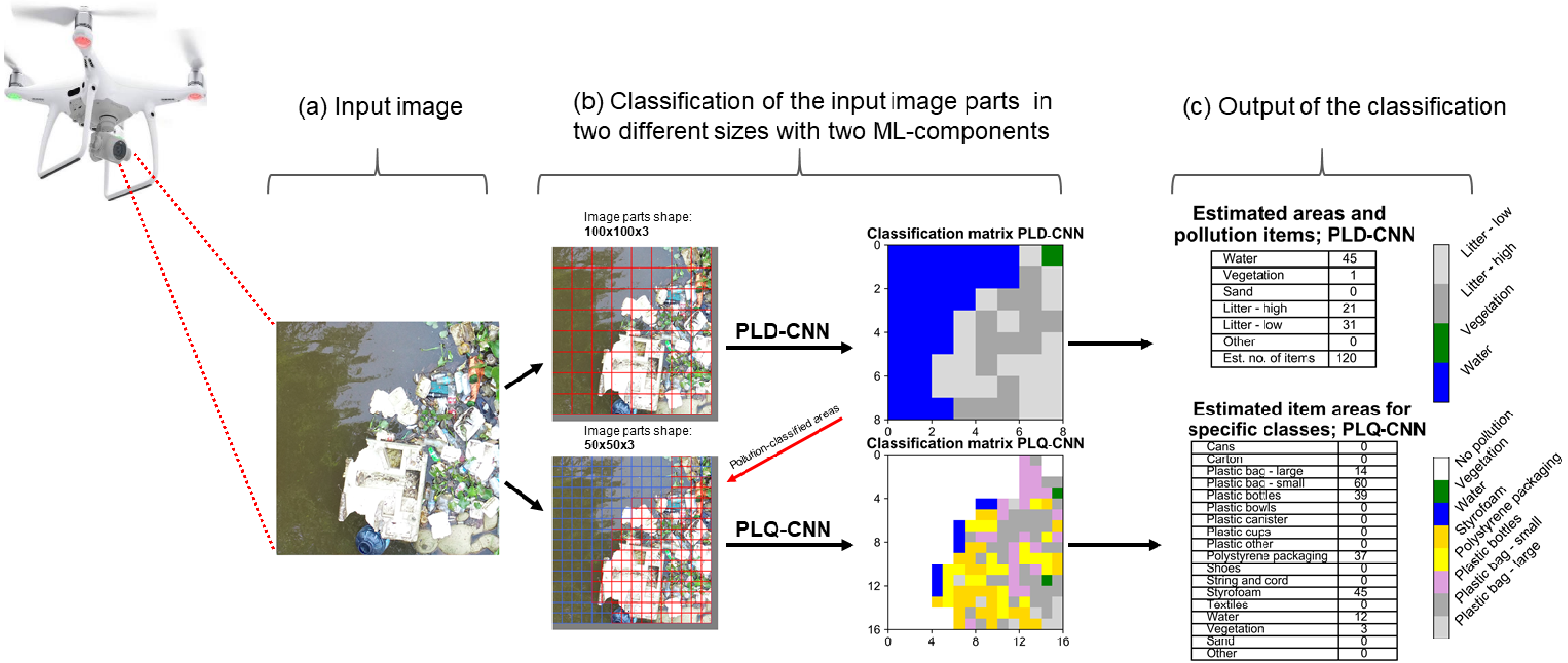
Published Works

- Machine learning approaches using Convolutional Neural Networks are being trained to detect and semi-quantify plastics.

- RGB imagery was from a DJI drone survey and validation was done using in-situ counts.

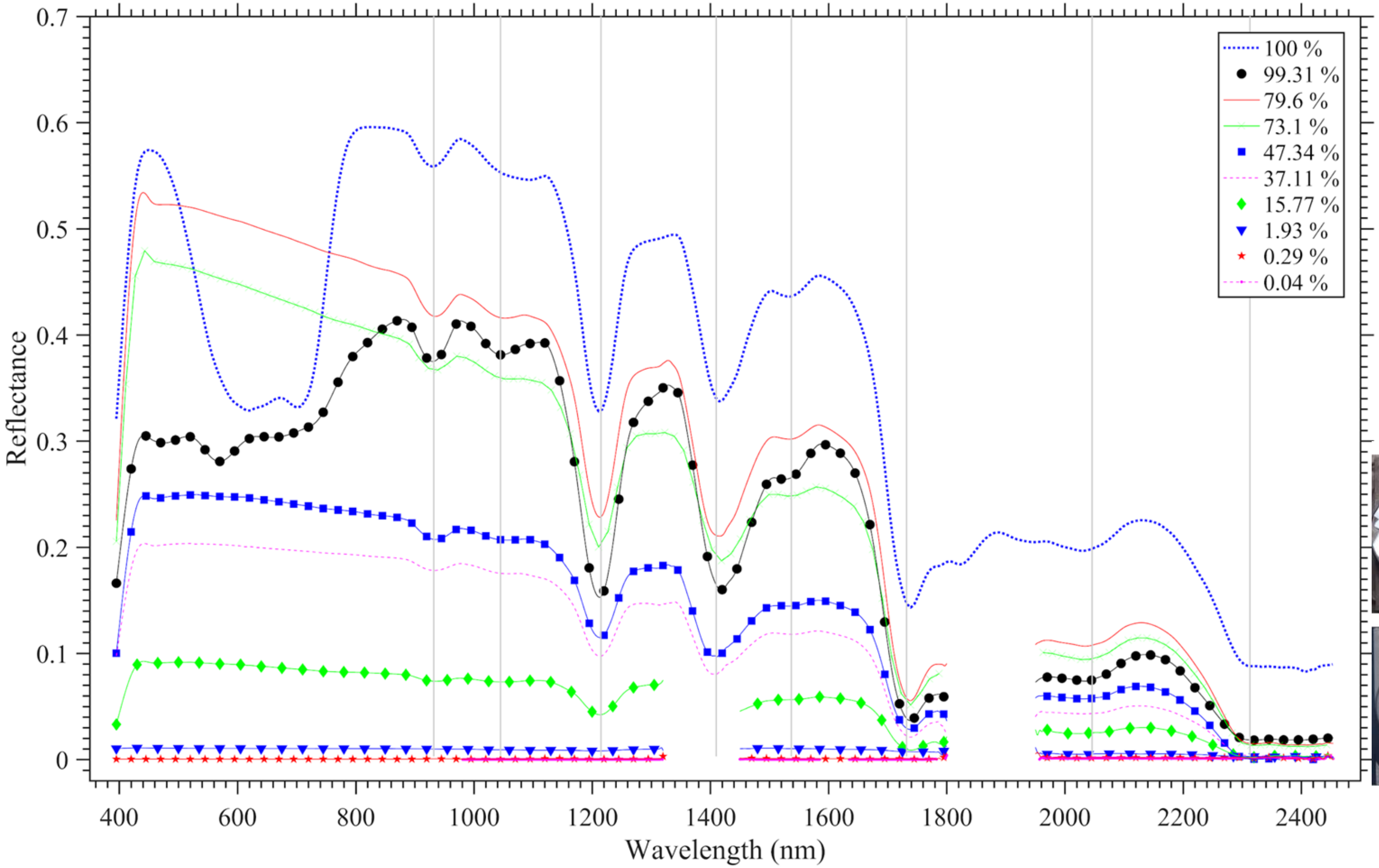


Wolf et al., 2020

Carl von Ossietzky Universität Oldenburg

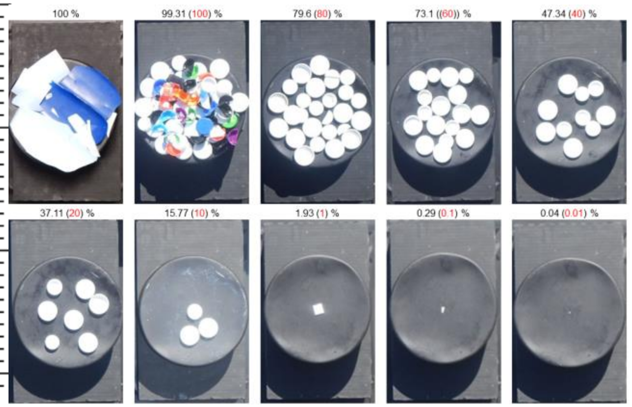
Published Works

- Apparent colour of object affects the reflectance shape and magnitude in the visible to shortwave infrared.
- At full pixel coverage, multi-coloured objects have lower reflectances compared to bright objects.



Vertical grey lines indicate absorption features ~ 931, 1045, 1215, 1417, 1537, 1732, 2046 and 2313 nm (Garaba and Dierssen, 2018) found in ocean-harvested plastic.

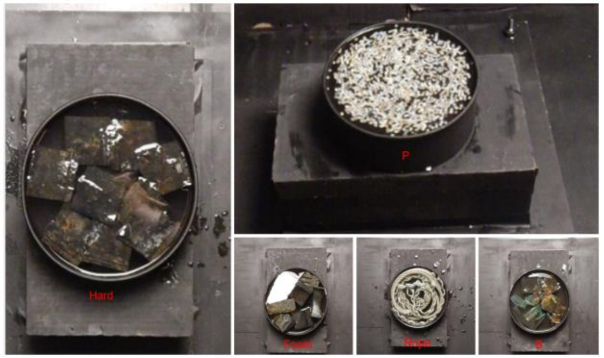
Virgin HDPE



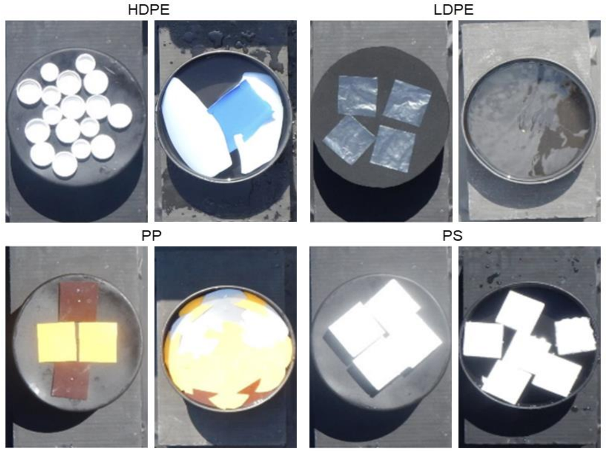
Garaba et al., 2021

Published Works

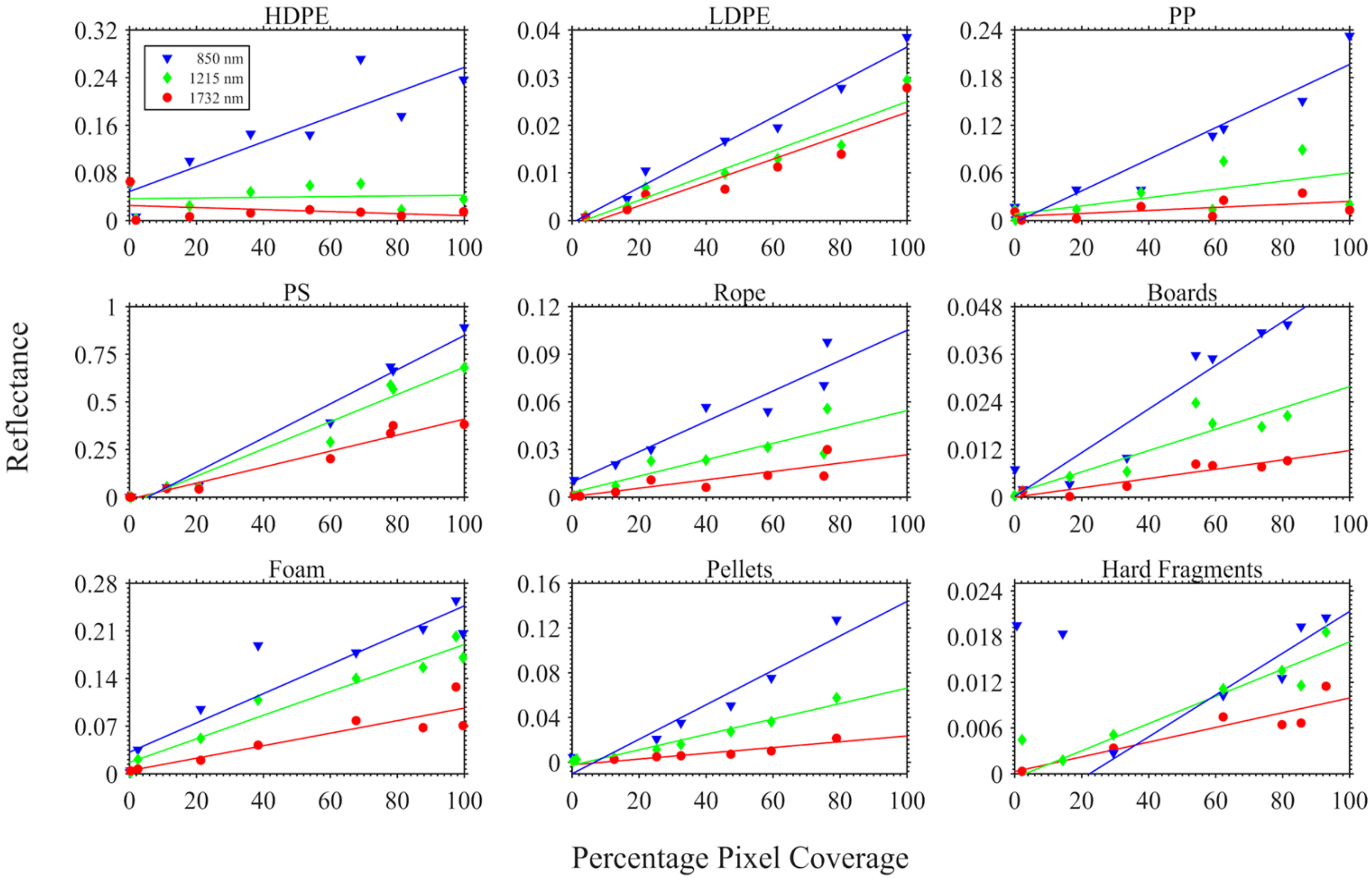
- Reflectance values were shown to be positively correlated to the pixel percentage coverage.



Ocean-harvested plastics from the Great Pacific Garbage Patch.



Virgin plastics typical in household waste.



Garaba et al., 2021

Research Gaps

- The IOCCG Task Force will aim to address key areas of interest.

LIDAR

Thermal Imaging

Microwave

Radar

Radio Frequency

Spatial and Spectral Resolution

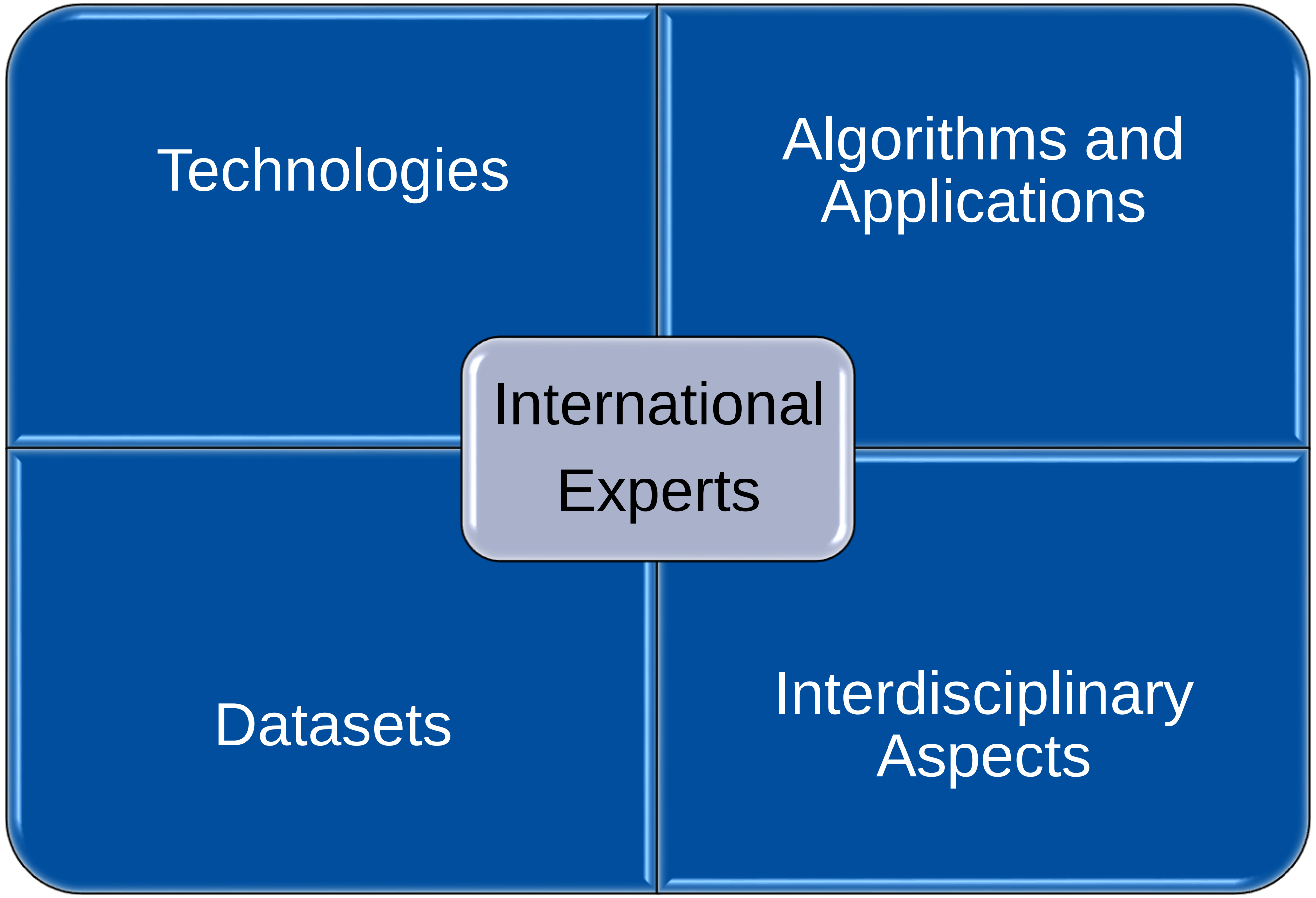
Hyperspectral

Multispectral

Related Geophysical Variables

Drone, Airborne and Satellite data

Protocols



Machine Learning

Detection

Identification

Tracking

Quantification

Qualitative Mapping

How can remote sensing support stakeholder?

Carl von Ossietzky Universität Oldenburg

Thank you for your time!

A microplastic beaching event in Kailua, Oahu, Hawaii, USA.

Acknowledgements

- Funding from European Space Agency and the German Research Foundation (DFG) is greatly appreciated.

- A big thank you to all collaborators in different projects.

- Contact me via email shungu.garaba@uol.de

Selected Publications

- **Biermann**, L., Clewley, D., **Martinez-Vicente**, V., **Topouzelis,** K. (2020) Finding plastic patches in coastal waters using optical satellite data. **Scientific Reports**, v. 10, no. 1,p. 1–10.

- van Sebille, E., Aliani, S., Law, K. L., Maximenko, N., Alsina, J., Bagaev, A., Bergmann, M., Chapron, B., Chubarenko, I., Cózar, A., Delandmeter, P., Egger, M., Fox-Kemper, B., **Garaba**, S. P., Goddijn-Murphy, L., Hardesty, D., Hoffman, M. J., Isobe, A., Jongedijk, C., Kaandorp, M., Khatmullina, L., Koelmans, A. A., Kukulka, T., Laufkötter, C., Lebreton, L., Lobelle, D., Maes, C., **Martinez-Vicente**, V., et al. (2020) The physical oceanography of the transport of floating marine debris. **Environmental Research Letters**, v. 15, no. 2, p. 023003(1-32).

- **Garaba, S. P.**, and Dierssen, H. M (2020) Hyperspectral ultraviolet to shortwave infrared characteristics of marine-harvested, washed-ashore and virgin plastics. **Earth System Science Data**, v. 12, no. 1, p. 77-86.

- Maximenko, N., **Corradi**, P., Law, K. L., van Sebille, E., **Garaba, S. P.**, Lampitt, R.; Galgani, F.; **Martinez-Vicente** V. et al. (2019) Towards the integrated marine debris observing system. **Frontiers in Marine Science**, v. 6, no. 447.

- **Martínez-Vicente**, V., Clark, J.R., **Corradi**, P., Aliani, S., **Arias**, M., Bochow, M., Bonnery, G., Cole, M., Cózar, A., Donnelly, R., Echevarría, F., Galgani, F., **Garaba, S.P.**, et al. (2019) Measuring Marine Plastic Debris from Space: Initial Assessment of Observation Requirements. ***Remote Sensing****, v. 11, no. 20, p. 2443*.

- **Topouzelis, K.,** Papakonstantinou, A. and **Garaba, S. P.** (2019) Detection of floating plastics from satellite and unmanned aerial systems. **International Journal of Applied Earth Observations and Geoinformation**, v. 79, p. 175-183.

- **Garaba, S. P.**, Aitken, J., Slat, B., Dierssen, H. M., Lebreton, L, Zielinski, O. and Reisser, J. (2018) Sensing ocean plastics with an air borne hyperspectral shortwave infrared imager. **Environmental Science & Technology**, v. 52, no. 20, p. 11699–11707.

- **Garaba, S. P.** and Dierssen, H. M. (2018) An airborne remote sensing case study of synthetic hydrocarbon detection using short wave infrared absorption features identified from marine-harvested macro- and microplastics. **Remote Sensing of the Environment**, v. 205, p. 224-235.

United States Contributions to Global Ocean Plastic Waste Meeting 3

BREAK

Please return at 2:15 pm EST / 11:15 pm PST

PML | Plymouth Marine Laboratory

Research excellence supporting a sustainable ocean

Plastic remote sensing: development of algorithms and sensors for marine plastics

Victor Martinez Vicente

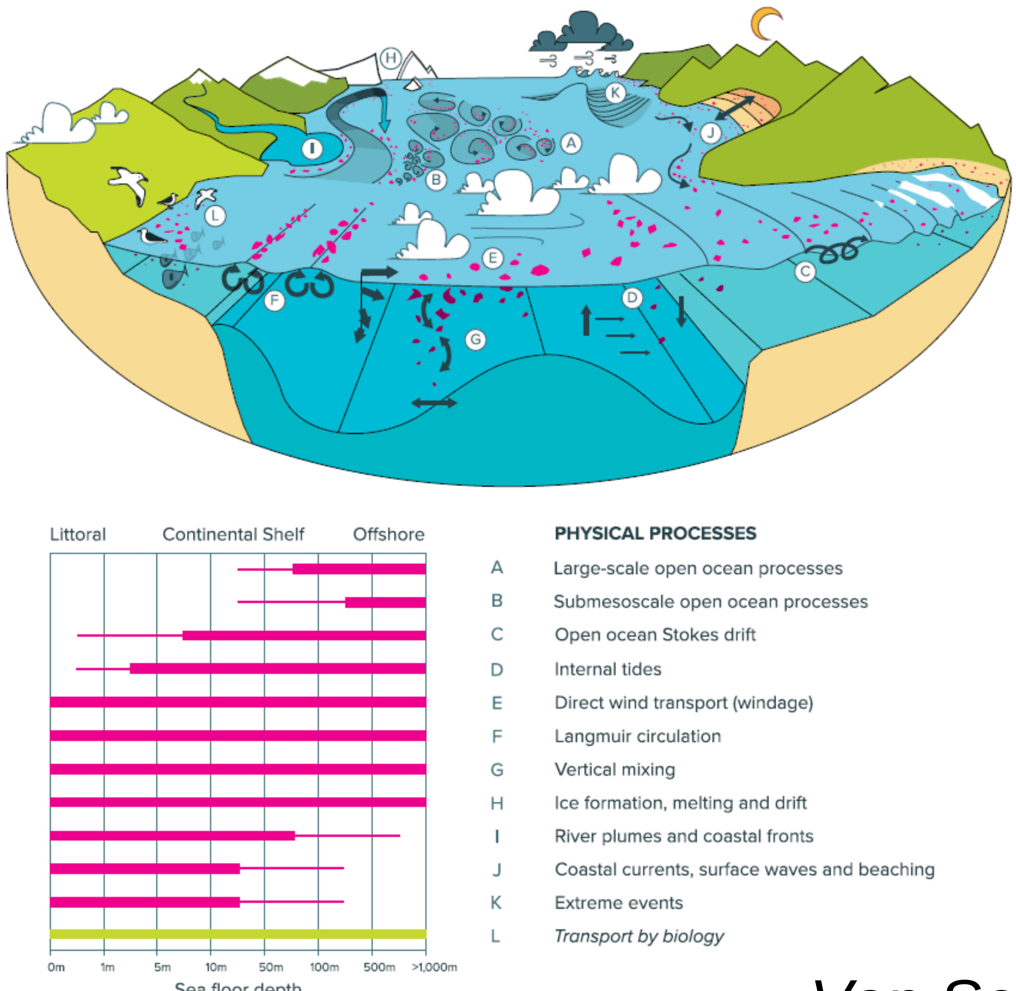
And PML team: L. Atwood, L. Biermann, J. Clark, M. Cole, A. Kurekin, P. Lindeque, A. Mata, P. Miller.

With contributions from P. Corradi (ESA), M. Arias (ARGANS)

Outline

- Context
- Observation scenarios for plastic from remote sensing
  - Frontal areas
  - Shoreline
  - Conclusions and limitations
- International collaboration
- Recommendations

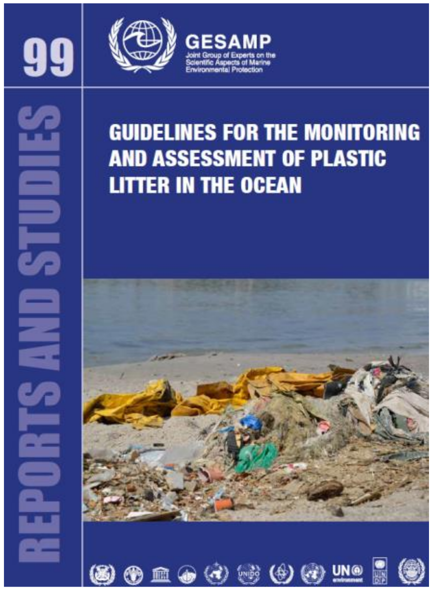
Marine litter transport occurs at different scales



Van Sebille et al.(2020)

Remote Sensing for Marine Policy

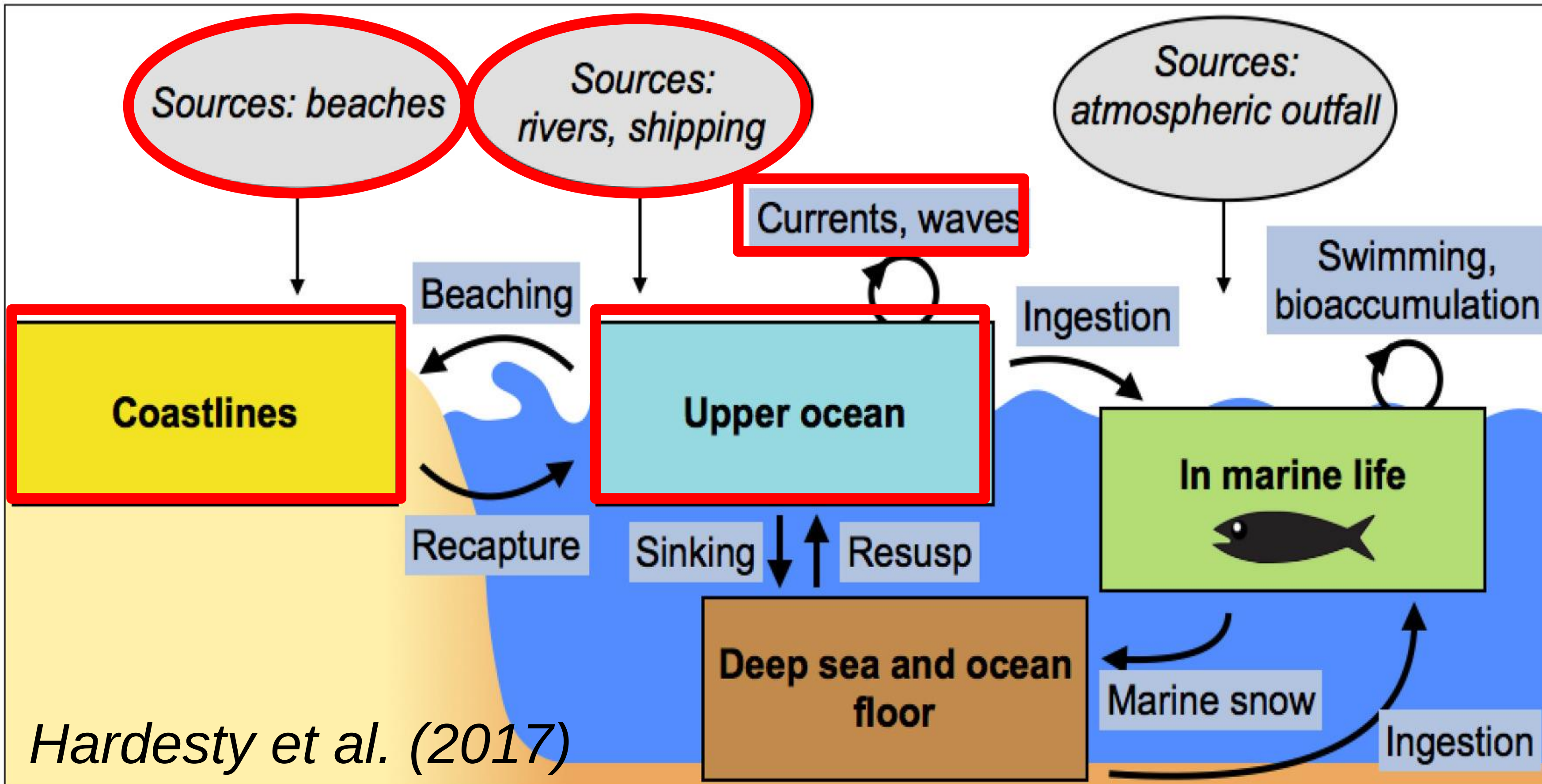
- EU Marine Strategy Framework Directive:
  - Shoreline
  - Seafloor
  - Water
  - Biota
  - Microlitter



- International recommendations (GESAMP)

- UN SDG indicators (14.1.1)

Remote sensing to support scientific questions



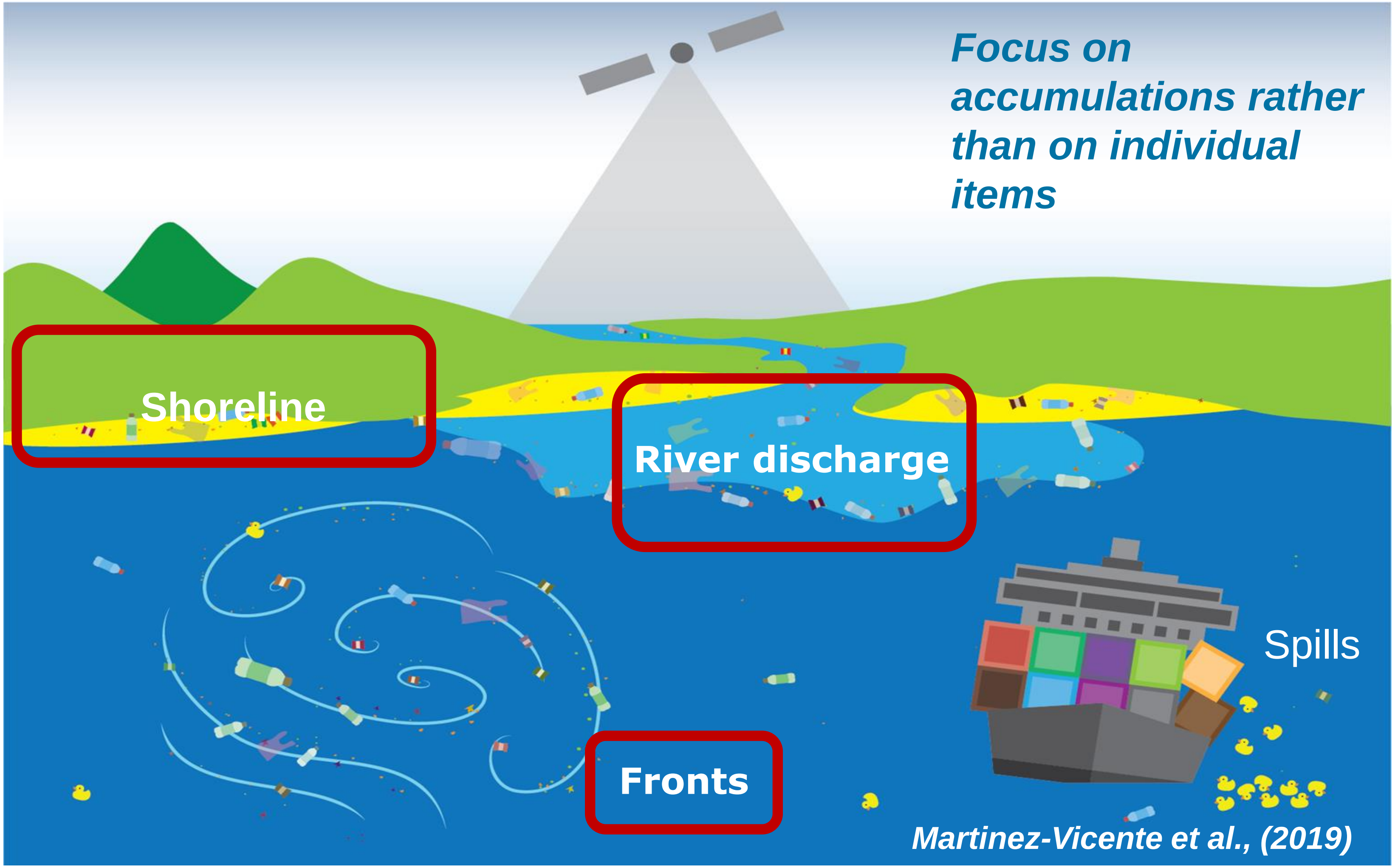
Hardesty et al. (2017)

Science led remote sensing design

- ✓ **Question 1 (Q1):** What are the magnitude, location and temporal variability of the sources and pathways into the marine environment of marine plastic debris?
- ✓ **Question 2 (Q2):** What are the abundance, horizontal distribution and composition of marine plastic debris, and how do these attributes change over time?
- ✓ **Question 3 (Q3):** Where does marine plastic debris tend to accumulate?
- ✓ **Question 4 (Q4):** How is marine plastic debris transported and what are the dominant physical processes influencing its fate?
- ✓ **Question 5 (Q5):** What role do biological, chemical and photochemical interactions play in controlling the movement and degradation of marine plastic debris?

Martinez-Vicente et al., (2019)

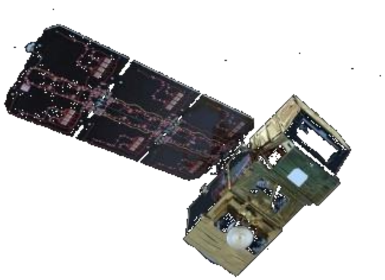
Observation Scenarios



Initial Traceability Matrix

Table 1. Major marine processes affecting the fate of marine plastic debris and their relevance to identified scientific questions (See the Introduction section). Spatial extent and lifetime of processes are reported alongside corresponding spatial and temporal sampling requirements [44]. Sampling requirements are reported in terms of threshold levels, see text for definition.

Marine Process	Spatial		Temporal		Related to Question (Q)
	Spatial Extent (max)	Required Spatial Resolution of Observations	Lifetime of Process (max)	Required Frequency of Observations	
River discharge	~100 km	~20 m	~1 month	at least every 12 h	Q1
Spills	~100 km	~20 m	~1 month	at least every 24 h	Q1
Shoreline accumulation	~1000 km	~20 m	~10 year	at least every 30 d	Q1, Q2, Q3
Submesoscale convergence filaments	~10 km	100 m	~10 d	at least every 24 h	Q2, Q3



Spatial resolution
10, 20, 60 m

Frequency
3-5 days

Sentinel-2 MSI

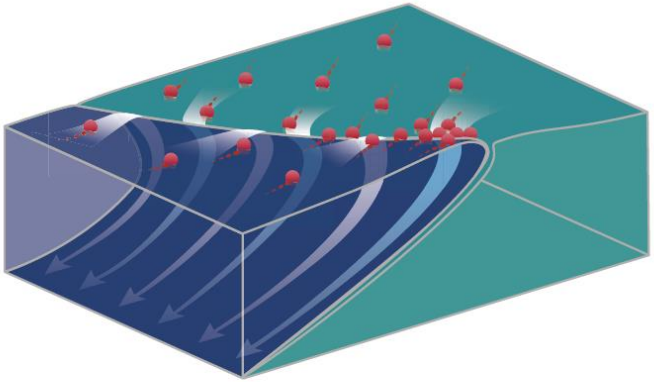
Martinez-Vicente et al.(2019)

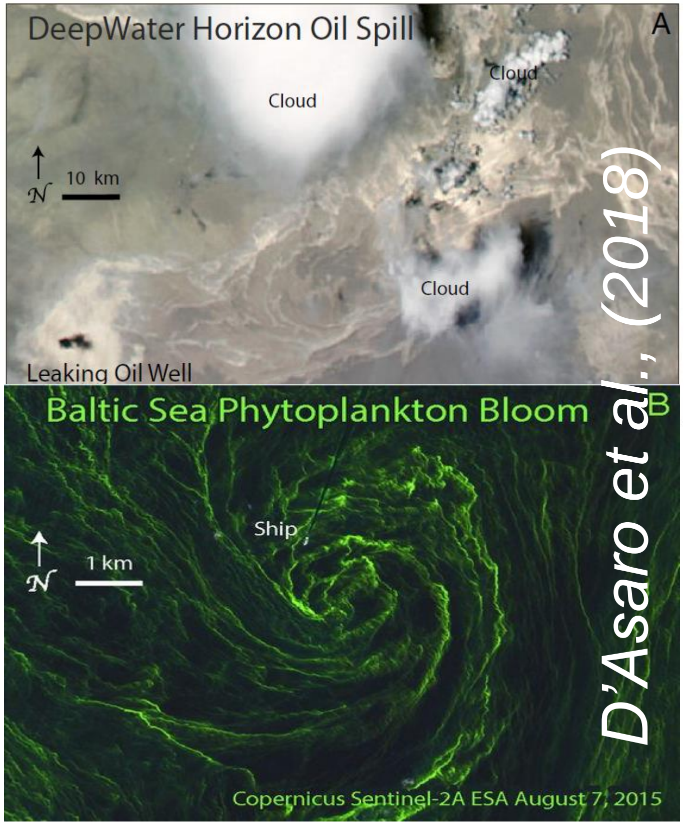
Frontal Areas

- Some frontal (submeso scale) structures have been shown to accumulate floating material. (D’Asaro et al., 2018)

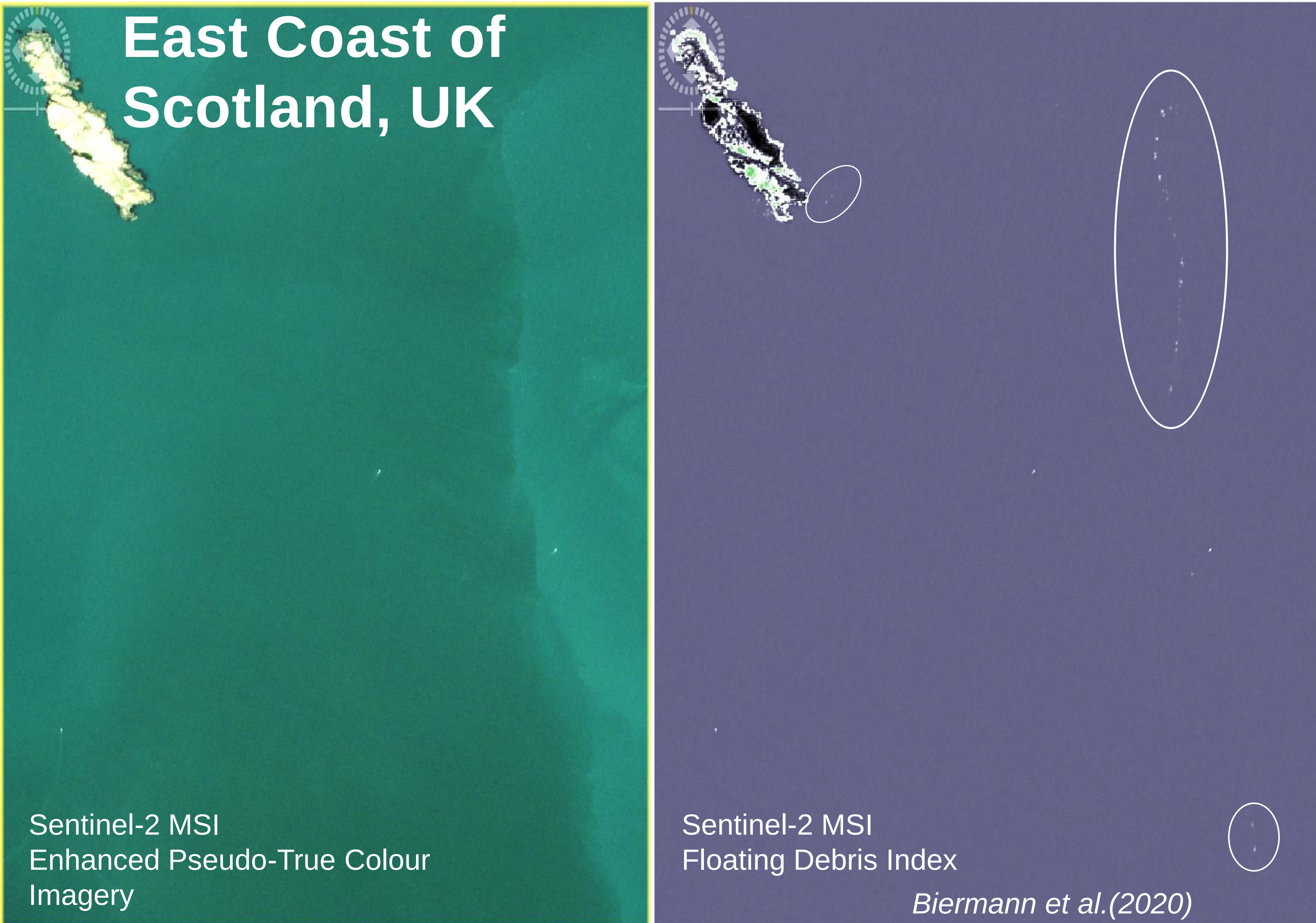
- Fronts act as **interaction hotspots** for plastic and marine life (Clark et al., 2016)

- Different motion scales may affect differently the size continuum of plastics





East Coast of Scotland, UK

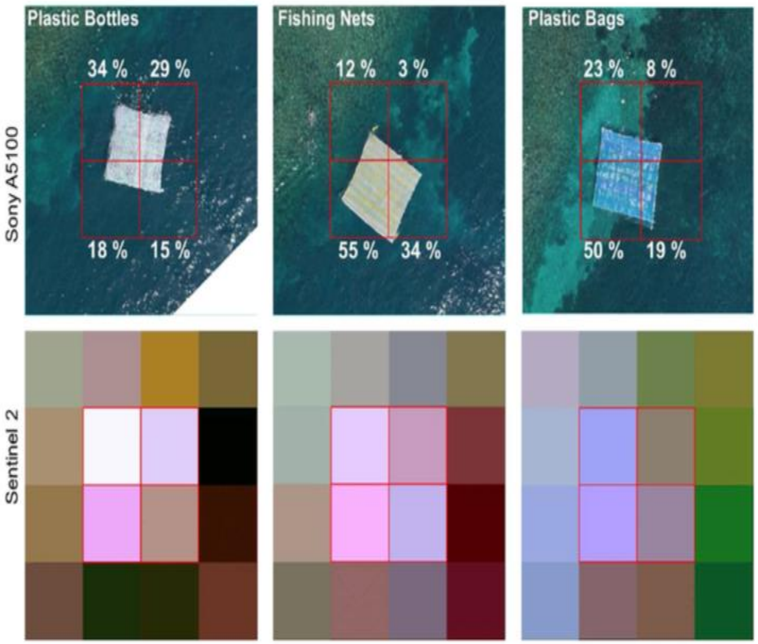


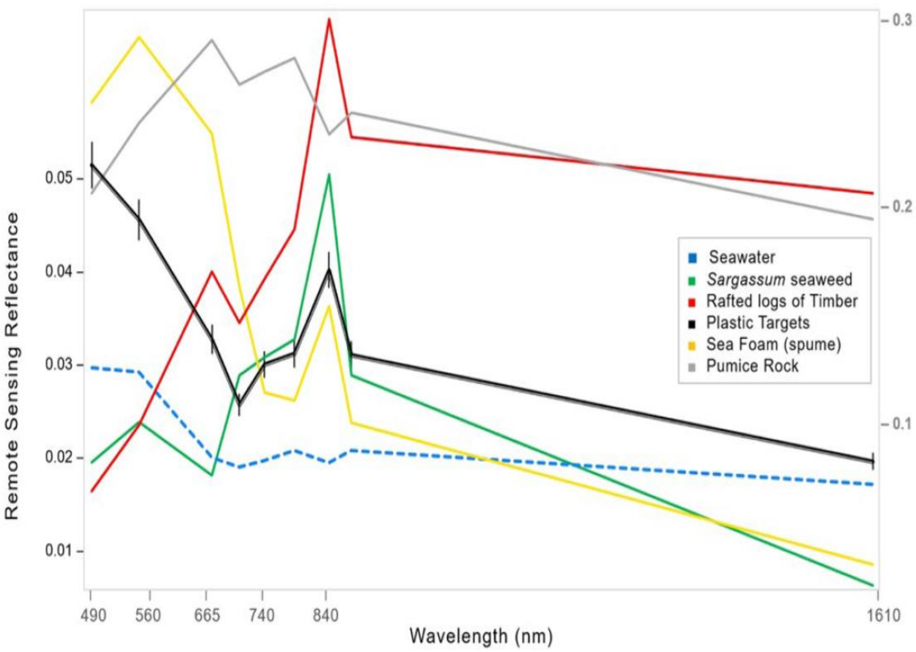
Sentinel-2 MSI
Enhanced Pseudo-True Colour Imagery

Sentinel-2 MSI
Floating Debris Index

Biermann et al.(2020)

Algorithms and spectral libraries



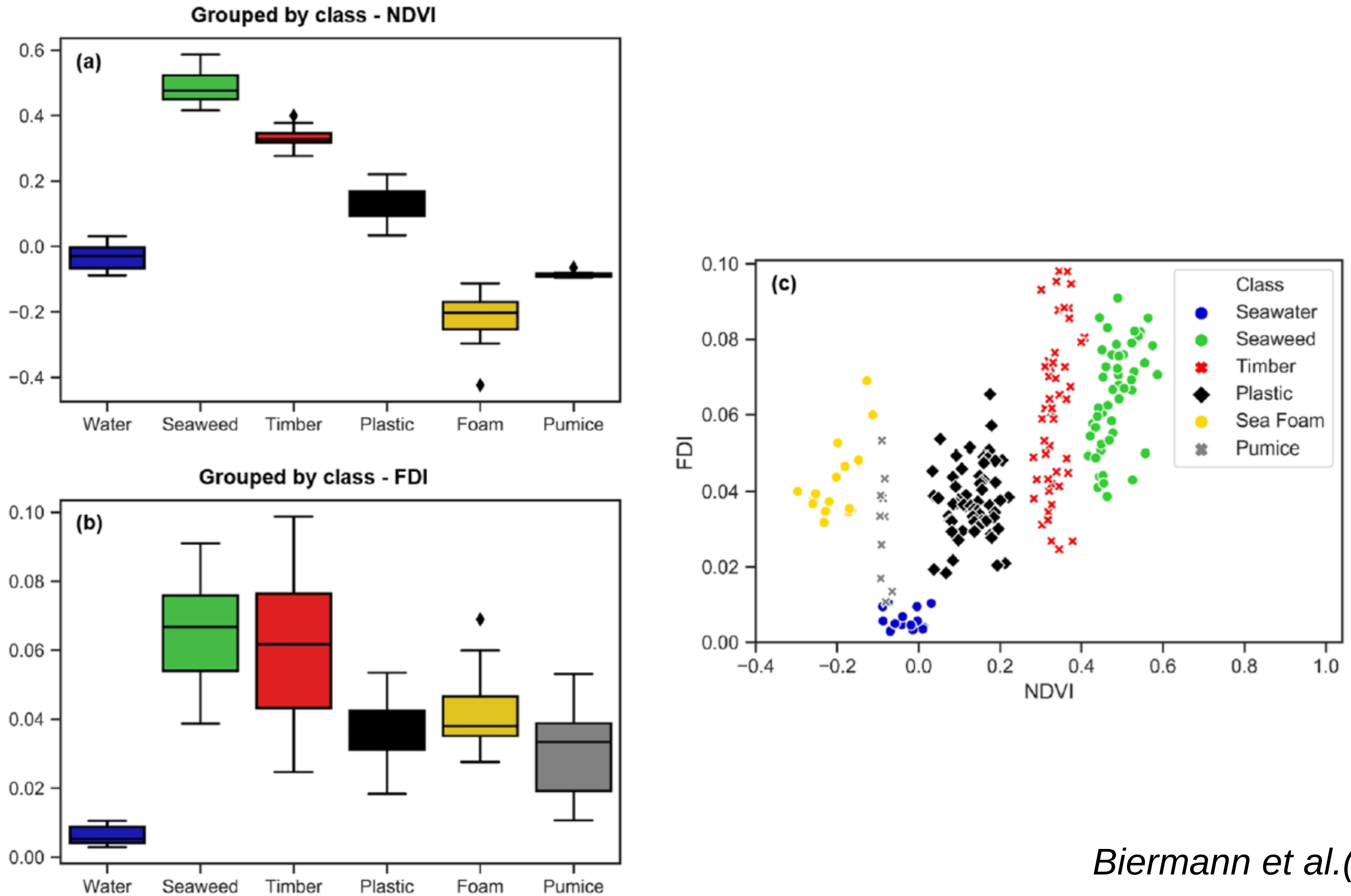


Topouzelis et al., (2019)

Biermann et al.(2020)

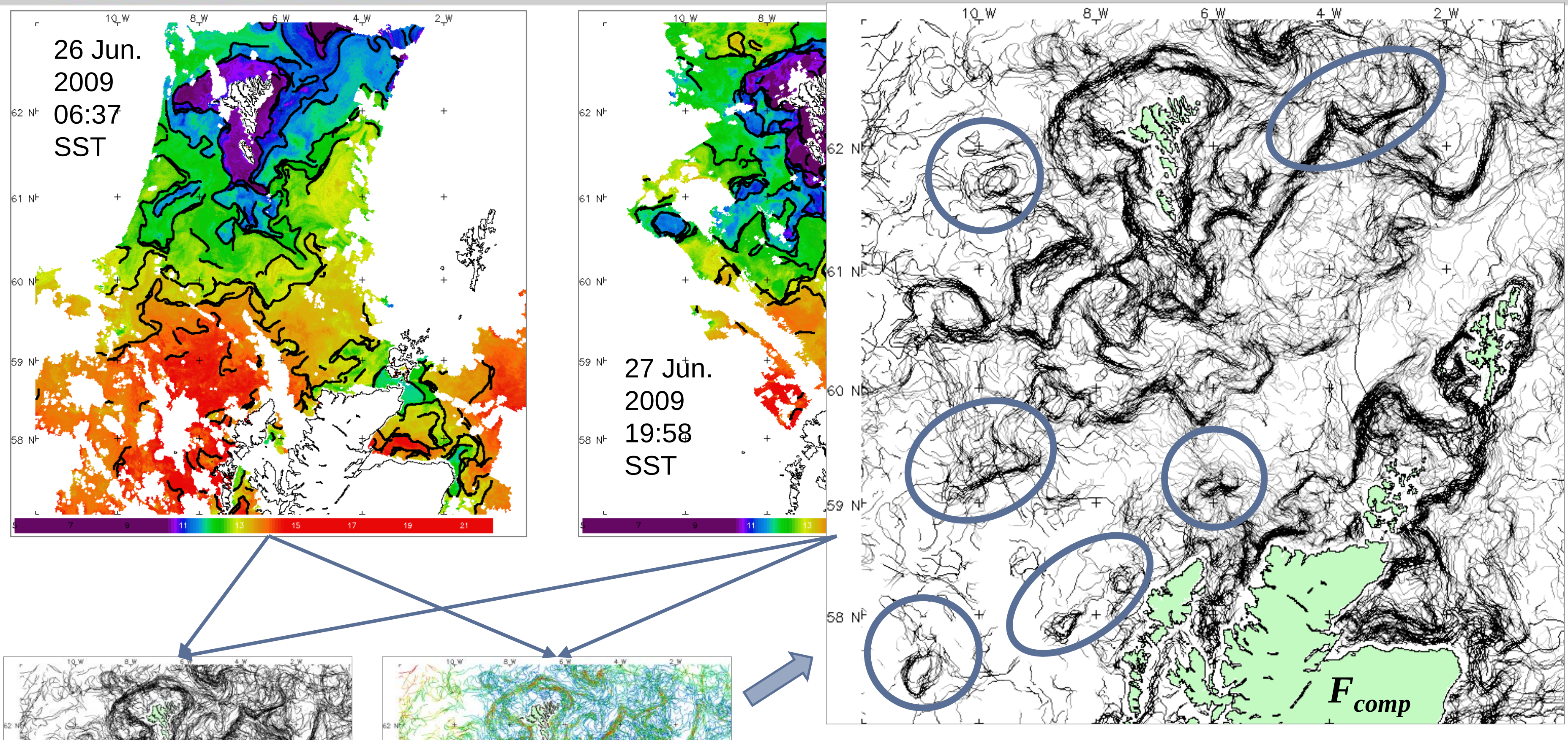
At least 30% pixel cover

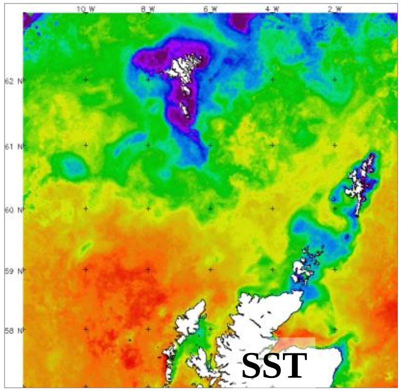
Training a Machine Learning algorithm to identify floating materials



Biermann et al.(2020)

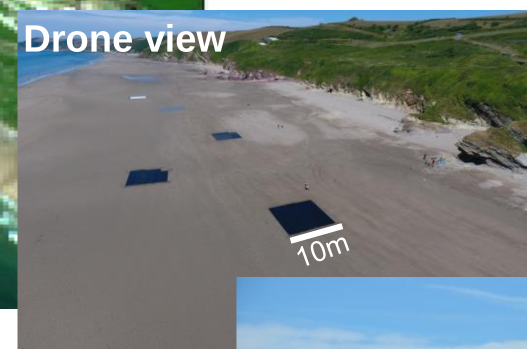
Satellite oceanic front detection

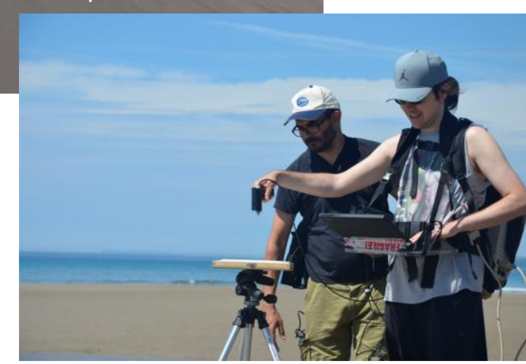




Miller, P.I., (2009) Composite front maps for improved visibility of dynamic oceanic fronts on cloudy AVHRR and SeaWiFS data, *Journal of Marine Systems*.

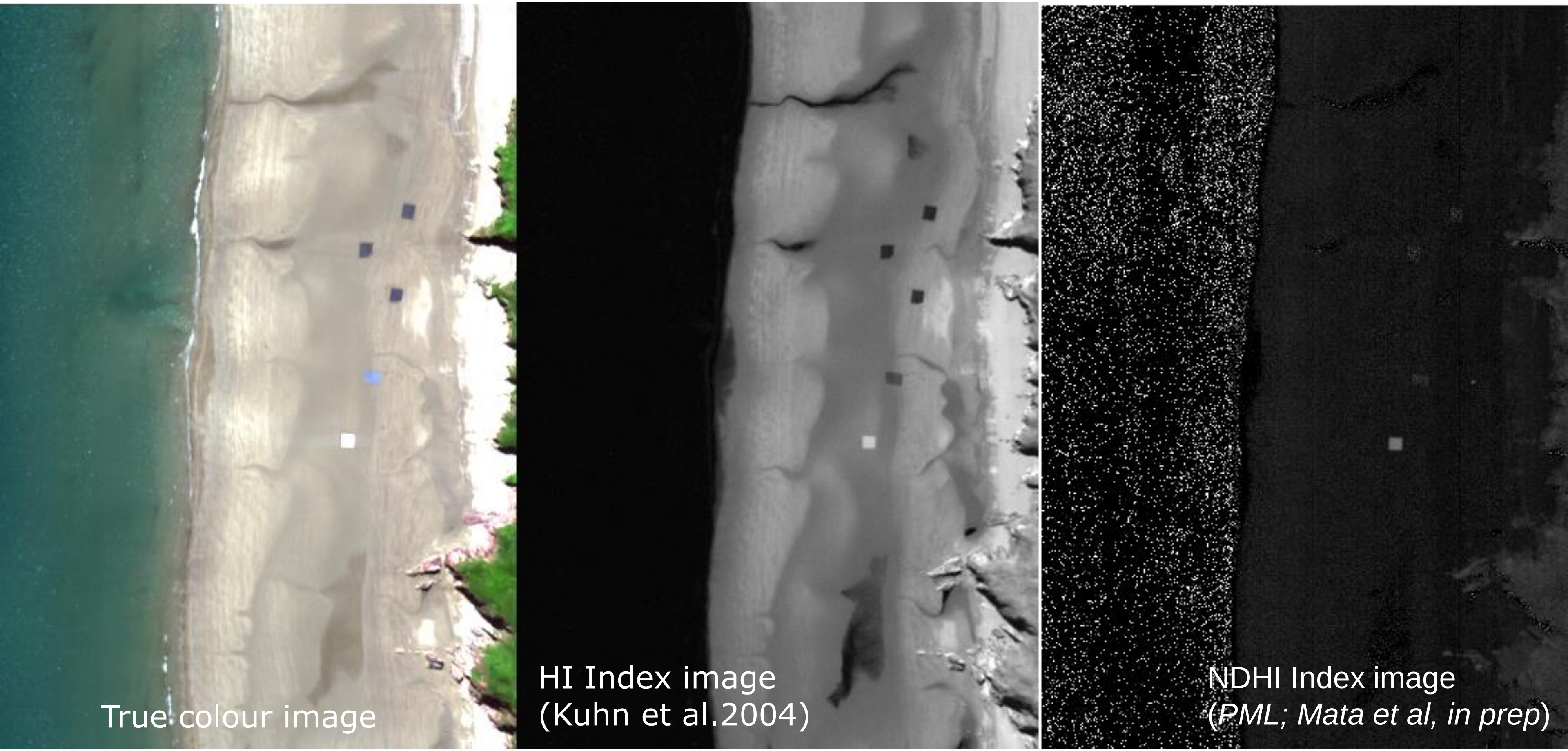
Shoreline





- Multi spectral sensor (MSI on S2)
- Hyperspectral sensor (on aircraft)
- RGB camera (Drone)

Airborne measurements with hyperspectral instruments



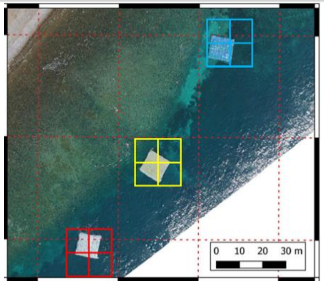
Current research: drones

- Drones used with RGB cameras to quantify plastics on beaches.
- Use of image analysis with machine learning.

- PML is working on exploiting spectral information to produce data suitable for satellite validation on the shore.

Martin et al.(2018)

Preliminary conclusions



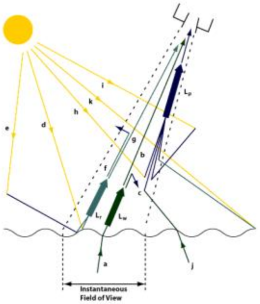
Source: Univ. of Aegean, PLP2018

- **Sub-pixel detection**: possible with multi-spectral sensor MSI in Sentinel-2.

$$FDI = R_{rs,NIR} - R'_{rs,NIR}$$
$$R'_{rs,NIR} = R_{rs,RE2} + (R_{rs,SWIR1} - R_{rs,RE2}) \times \frac{(\lambda_{NIR} - \lambda_{RED})}{(\lambda_{SWIR1} - \lambda_{RED})} \times 10$$

Biermann *et al.*, Sci. Rep. Nature 2020

- **Spectral indexes**: possible to build specific spectral indices for marine litter - need for combining optical and NIR/SWIR information, for (a) capture the litter signature and (b) discriminate false positives.

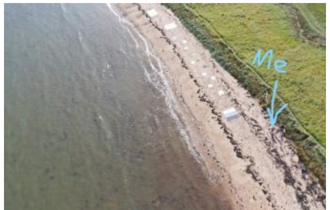


Source: I.S. Robinson

- **Atmospheric corrections**: impact on the signal in NIR/SWIR, which suppress the signature observed by space-based instruments in these bands.

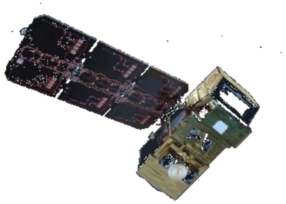
Source: C. Power, 2017

- **Accumulations**: Current sensor technologies enables detection of floating debris accumulations as proxy for plastic marine litter, e.g. windrows and fronts.

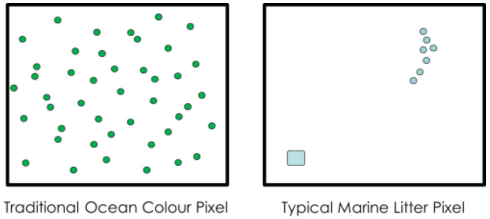


- **Dry-plastics:** detection using hyperspectral signatures is promising, testing is underway to produce standardized satellite validation datasets, aligned with future missions.

Limitations for passive optical remote sensing

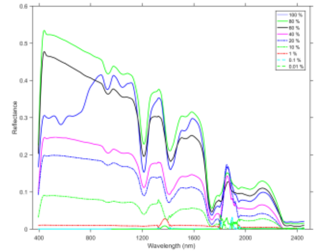


- **Current satellite sensors** not designed for detecting marine plastic pollution.



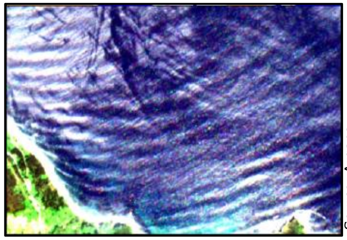
Source: Argans

- **Relatively low concentrations** of plastics and characteristic spatial distribution => low signal (and even more complex in coastal waters).



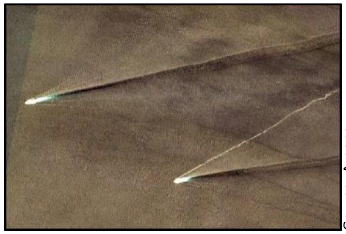
Source: S. Garaba et al., 2020

- **Different compositions and additives** give different visible spectral signature.



Source: Argans

- Signals from marine plastic are potentially part of the **“failing” pixels for current processing** (“bright pixels” due to high turbidity, foam, glint, contamination by atmospheric corrections, sea bottom, etc.).



Source: Argans

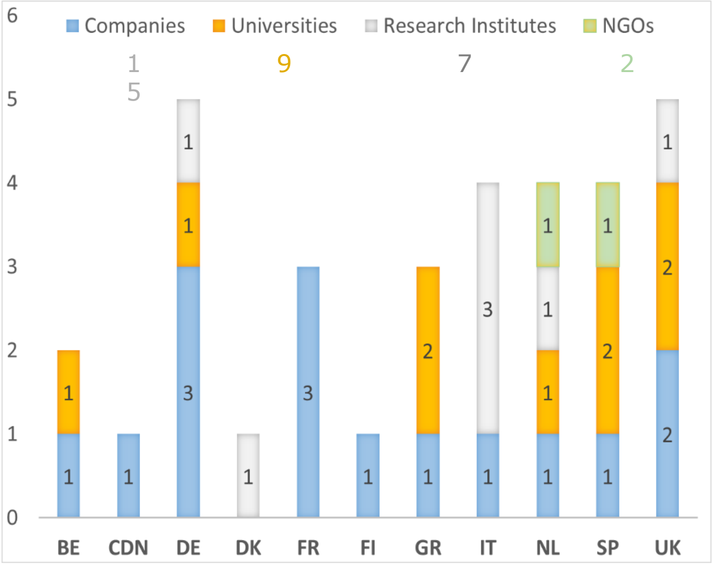
- Not unique identification of objects as plastic litter especially in coastal areas (**plastic ‘items’ in use, e.g. boats, buoys**, etc.).

International collaboration

- Delivery of a Marine debris observing system can not be constructed “from scratch” and separately from other global observing systems.
- International efforts to construct an Integrated Marine Debris Observing System (IMDOS) with remote sensing being an important part (*Maximenko et al. 2019*)
- Ongoing activities in Europe – European Space Agency (ESA)
- Opportunities for USA to collaborate to the global effort: initiated through SCOR and now continued through International Ocean Colour Coordinating Group (IOCCG) Task Team on marine debris.

Discovery Element – ESA Basic Activities Campaign on Remote Sensing of Plastic Marine Litter

- **~ 60** ideas received
- **26** selected proposals from companies, universities, institutes, NGOs of **11 Member States**

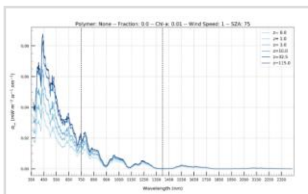


15 Early Technology Developments
10 Studies
1 Research co-sponsorship

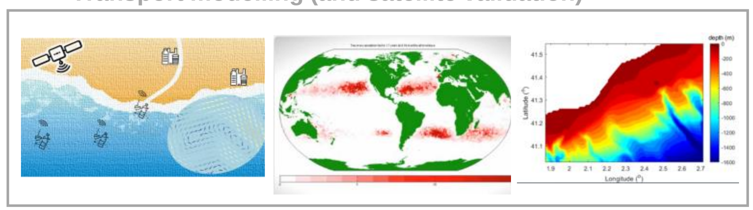
Clusters of projects

Technologies

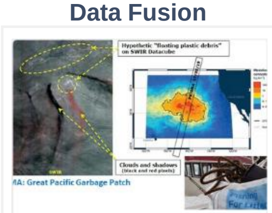
EO simulators



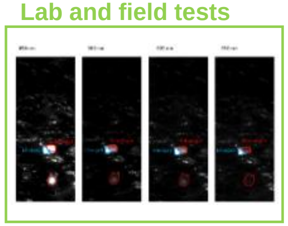
Transport modelling (and satellite validation)



Field tests and Sat Data Fusion

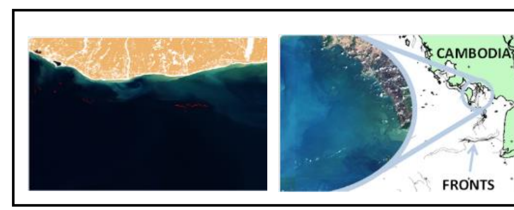


Lab and field tests



Validation Targets

Satellite detection of windrows and fronts

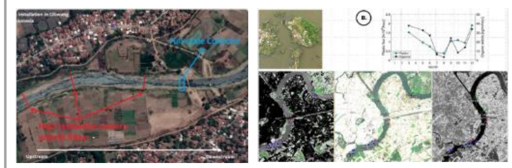


Clusters of projects

Airborne

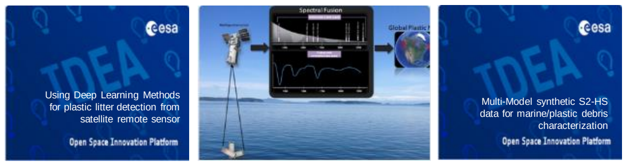
Shoreline

Rivers

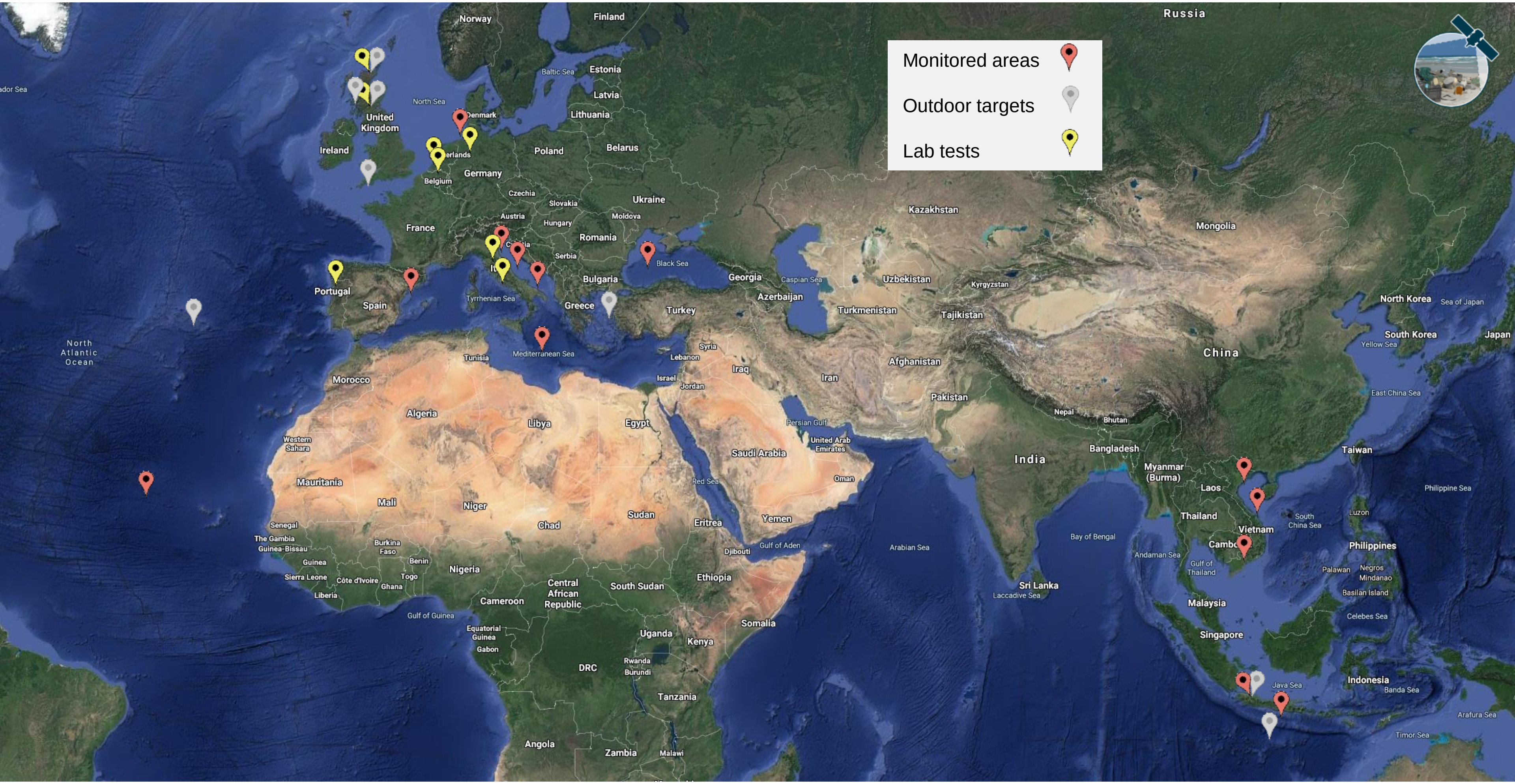


Multi-approach combining different platforms / technologies / AI / transport modelling

Data processing and AI



EO-ground truth Database



There is a large geographical gap for studies, where USA have a large role.

International coordination: IOCCG Task Force on Remote Sensing of Marine Litter and Debris

Recommendations

1. Rapidly evolving field of multidisciplinary research
2. Results indicate potential for detection of floating aggregates of plastic marine debris.
3. Focus international collaboration on:
    1. Technologies: techniques (e.g., hyperspectral, SAR) and platforms (citizen science, cubesats, HAPS)
    2. Algorithms and applications: atmospheric correction, machine learning, scenarios (e.g. river outflows and cargo spills)
    3. Datasets: best practices, openly accessible relevant lab and in situ datasets
    4. Interdisciplinary aspects: feedback from stakeholders, dissemination
4. Contribution through IOCCG Task Team to IMDOS activities

Acknowledgements

- ESA for funding for OPTIMAL, RESMALI, SIMPLER, FRONTAL, HyperDRONE
- UK national funding
  - ACCORD – NERC
  - NEODAAS – NERC
- SCOR WG153: Floating Litter and its Oceanic TranSport Analysis and Modelling (FLOTSAM, http://scor-flotsam.it/)
- IOCCG Task Force on Marine Debris

Thank you

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Remote Sensing for Marine Plastic Pollution

Ellen Ramirez | Supervisory Scientist

NASEM | 28 January 2021

United States Contributions to Global Ocean Plastic Waste - Statement of Task 4.

- Assess the potential value of a national marine debris tracking and monitoring system and how such a system might be designed and implemented.

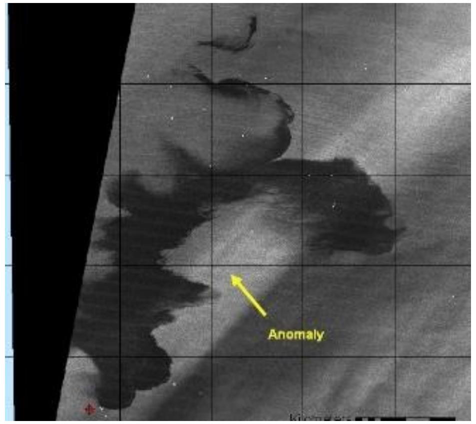
a. consider how the tracking and monitoring system could be used to identify priorities for source reduction and cleanup, assess progress in reducing US contribution to global ocean plastic waste, and determine which existing systems or technologies would be most effective for reducing inputs of plastic waste to the ocean.

b. assess how the Marine Debris Monitoring and Assessment Project protocols can inform a nationwide shoreline monitoring effort when implemented at greater spatial and temporal resolution

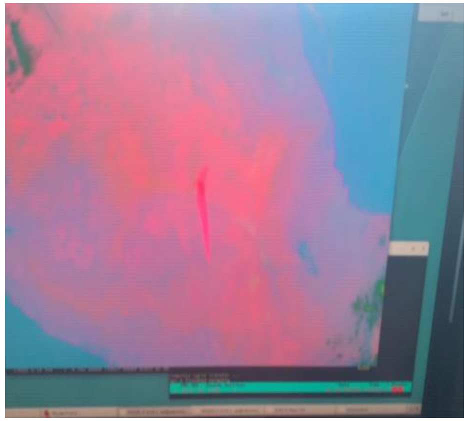
NOAA Satellite Analysis Branch

Fire and Smoke

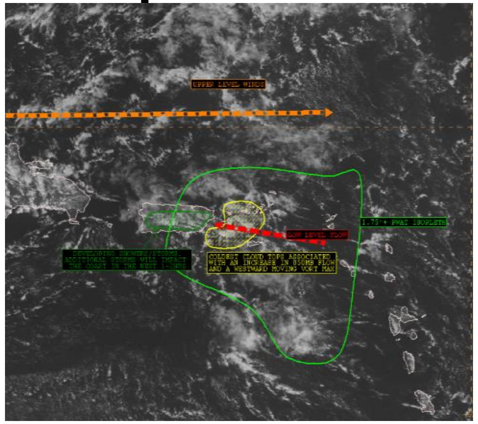
Marine Pollution



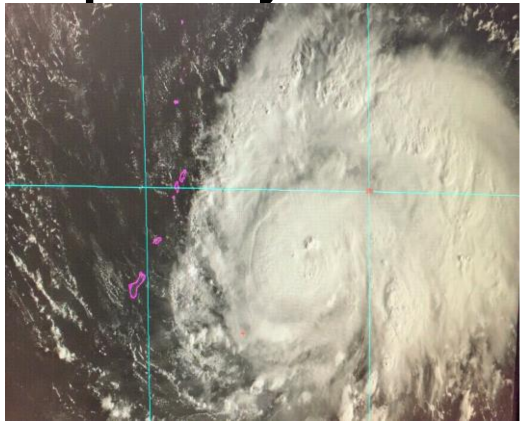
Volcanic Ash

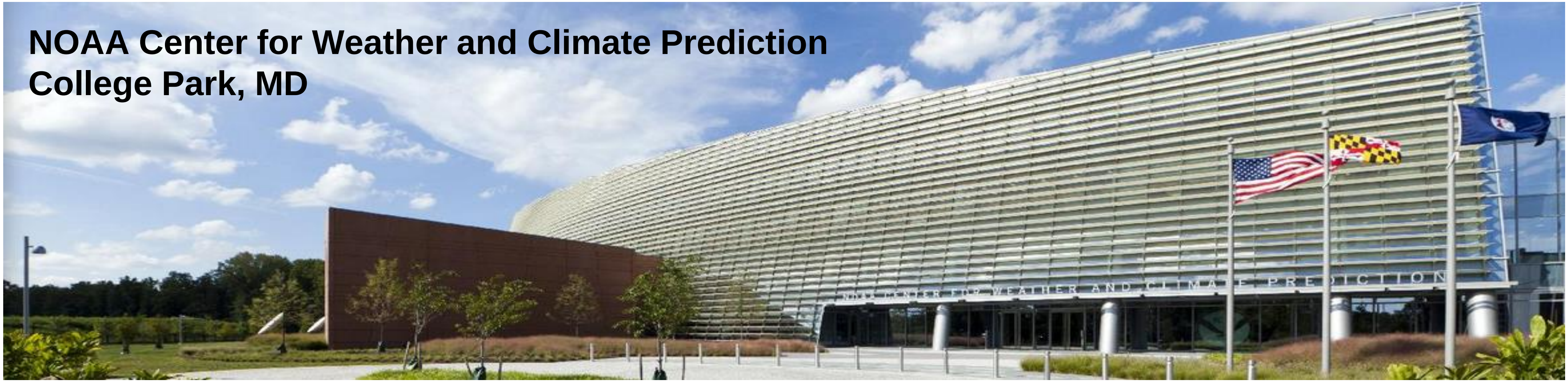


Precipitation



Tropical Cyclone

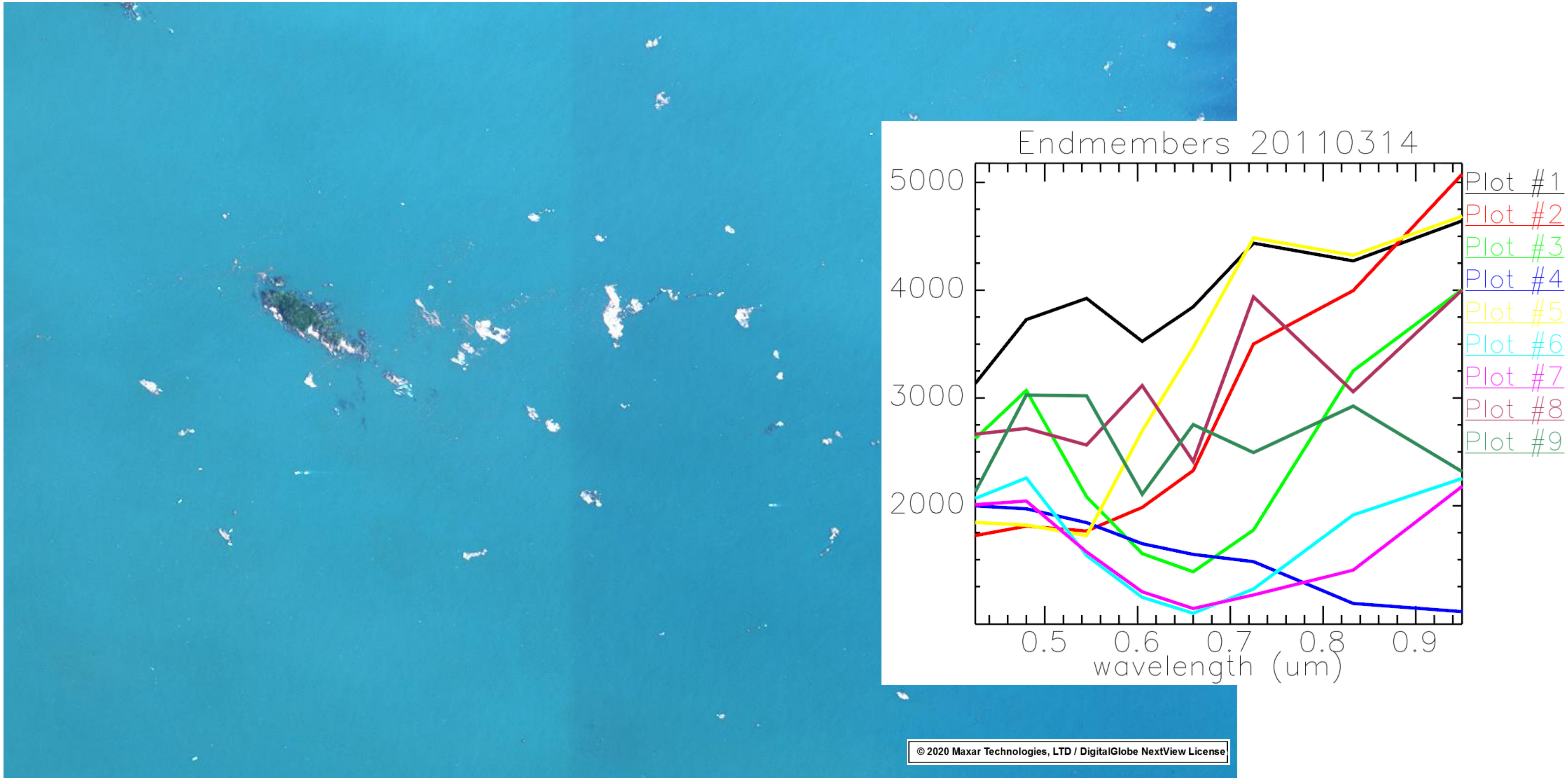




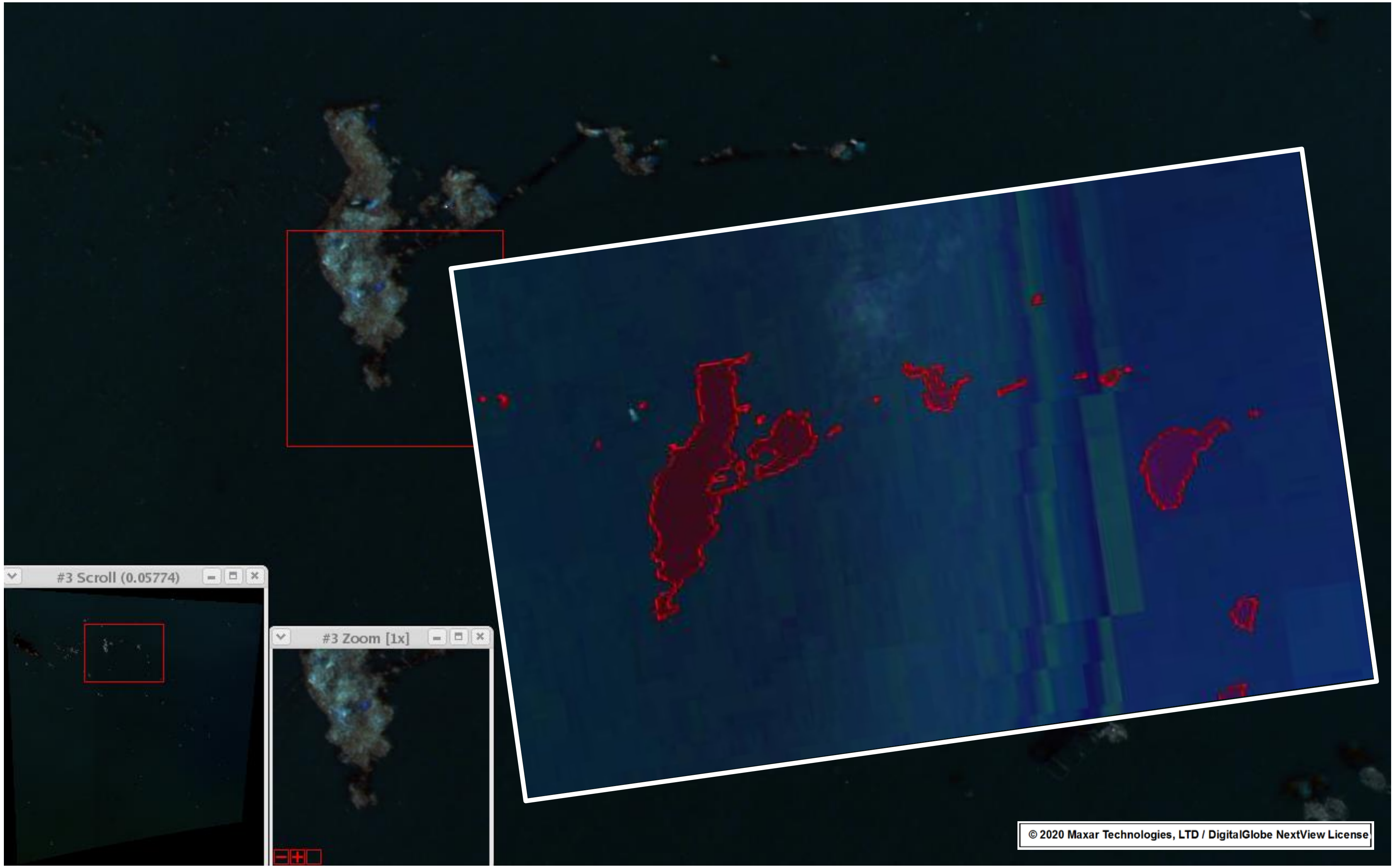
NOAA Center for Weather and Climate Prediction
College Park, MD

2011 Japan Earthquake and Tsunami

Debris Rafts and Spectral Assessment



Target Detection



Current Efforts

MACROPLASTICS

Derelict Nets

Photo Credit: Ocean Voyages Institute

NOAA Debris Removal Efforts

Photo Credit: NOAA

Ground Verification

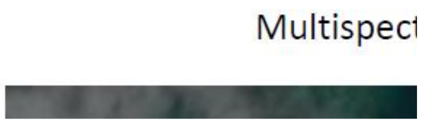
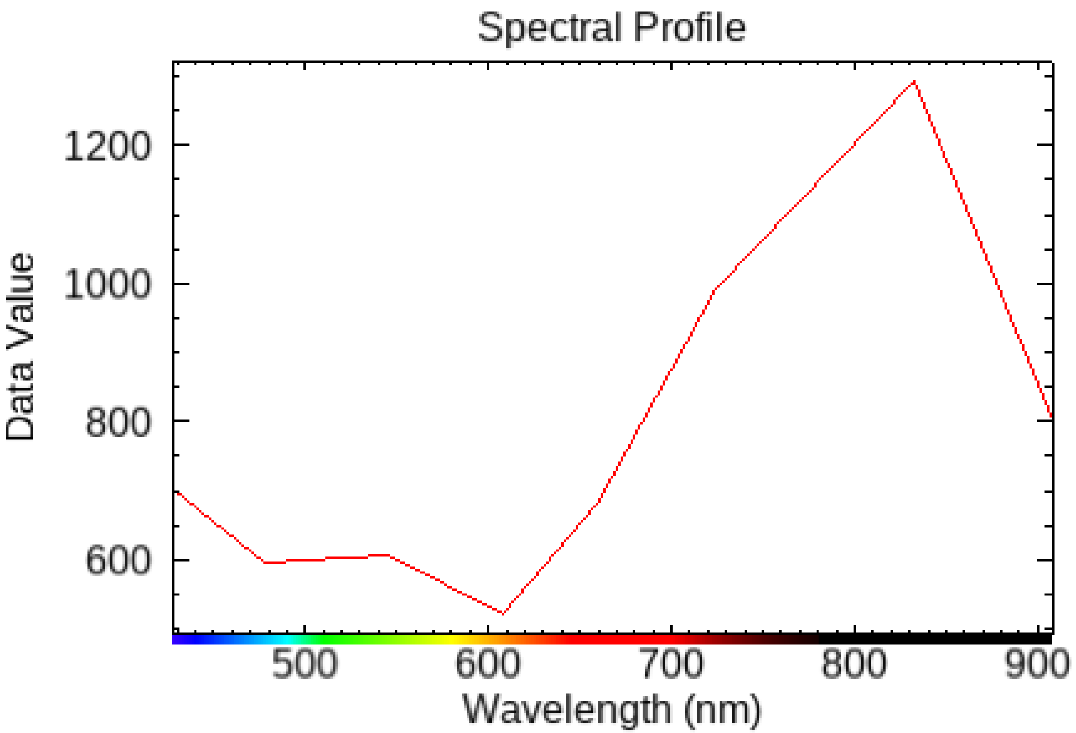
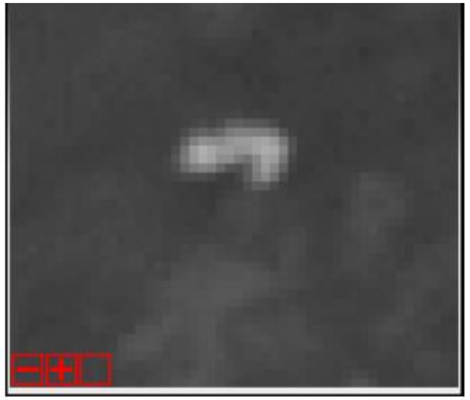


Photo Credit: NOAA





Spectral Peak at 840nm

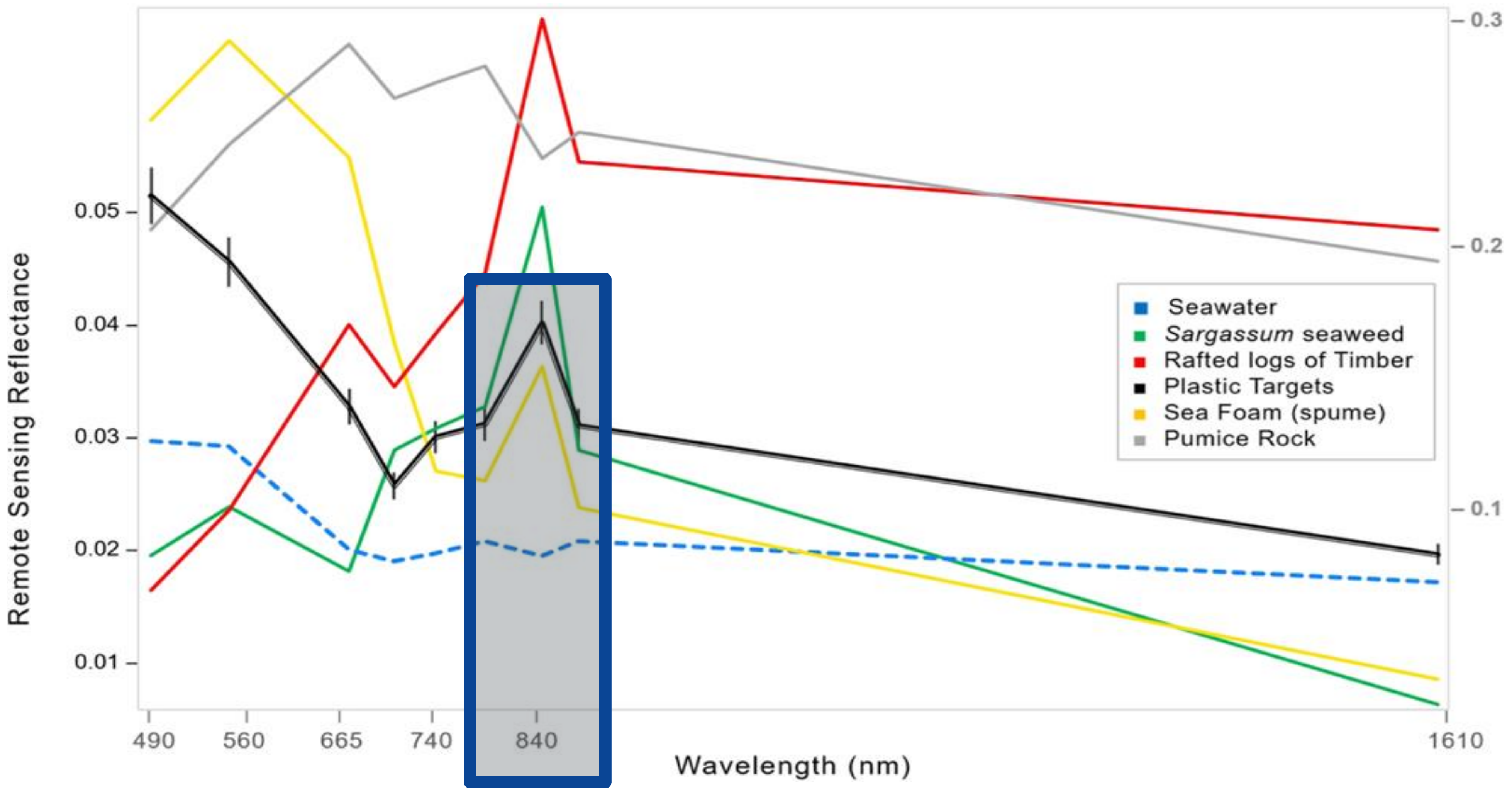
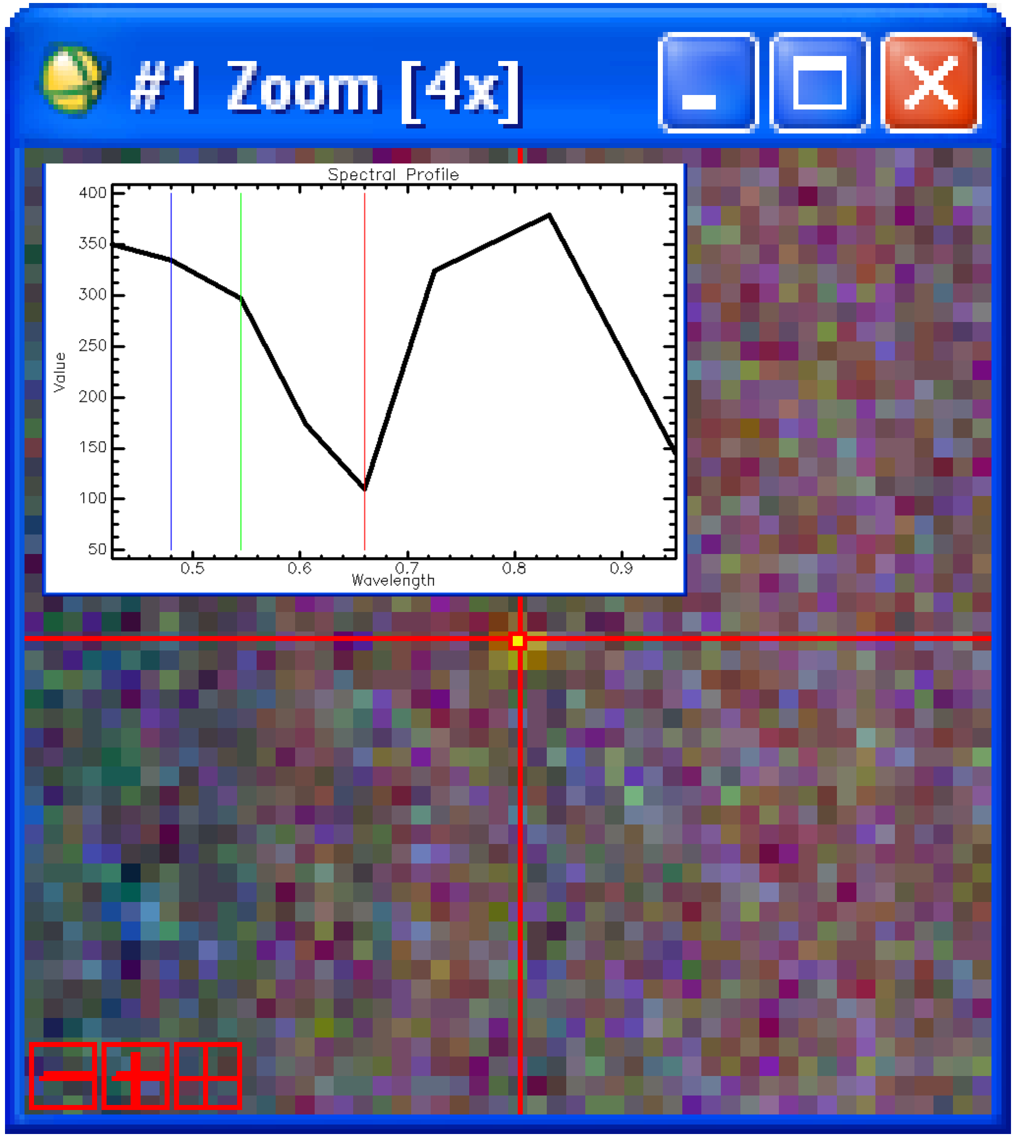
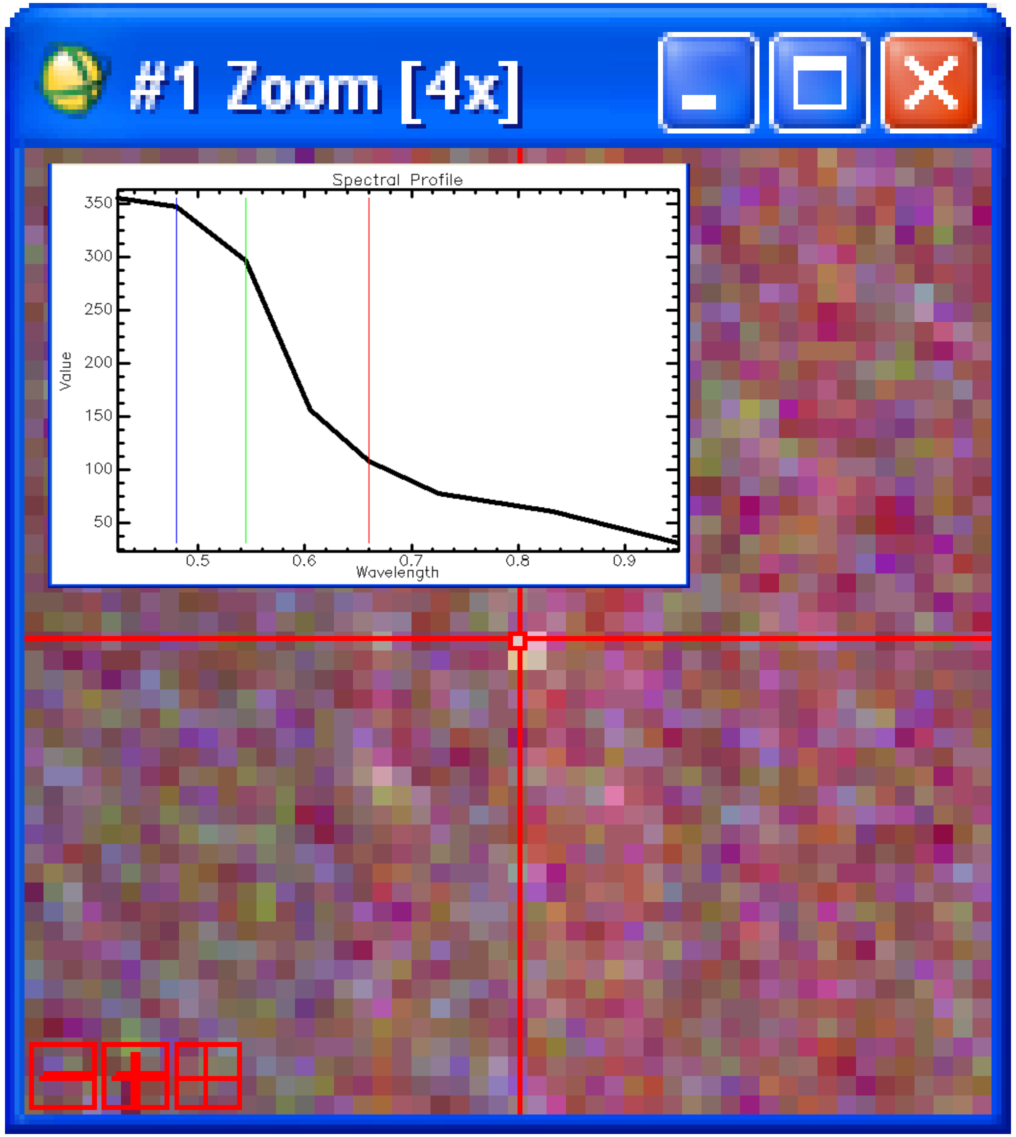


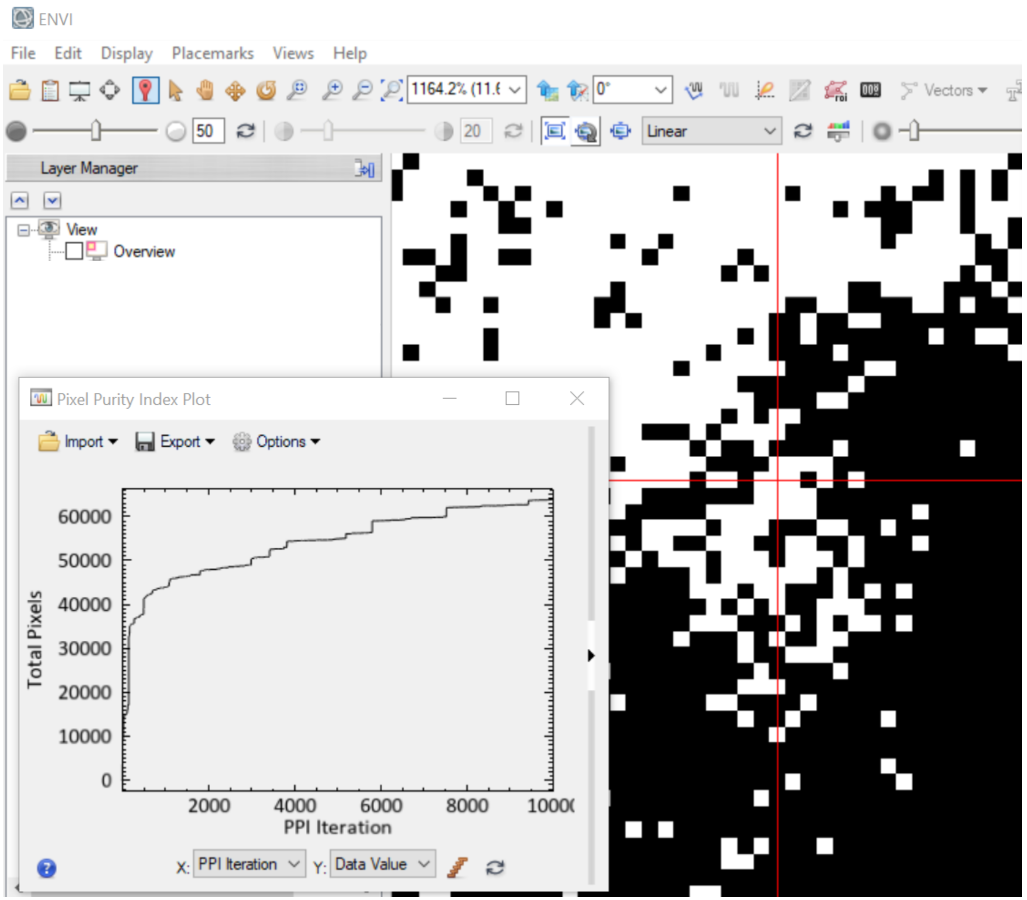
Figure from: Biermann, L., Clewley, D., Martinez-Vicente, V. *et al.* Finding Plastic Patches in Coastal Waters using Optical Satellite Data. *Sci Rep* **10,** 5364 (2020)

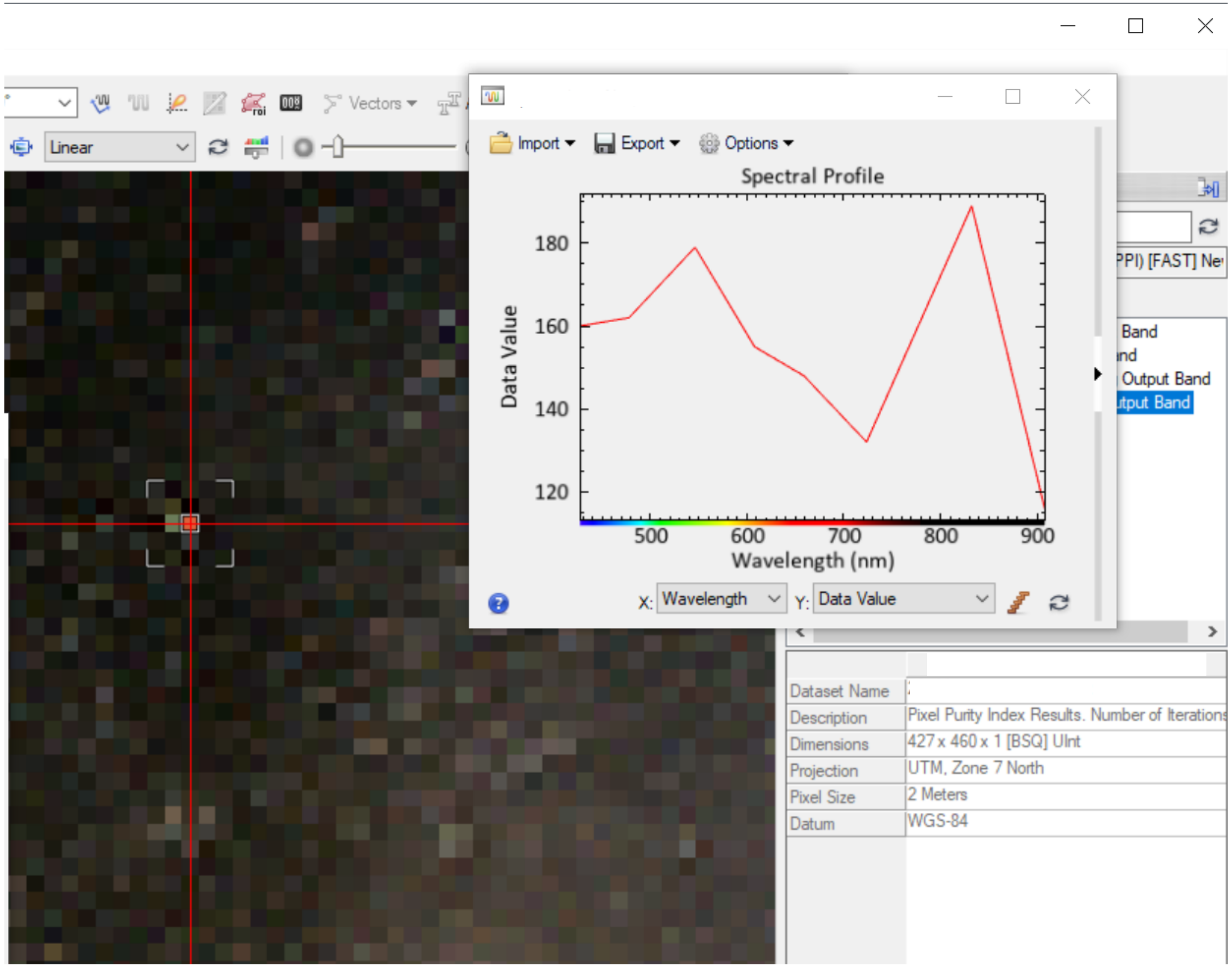
Visual vs. Spectral Inspection





Where Are We Now?





Recommendations

- Close data gaps – Non licensed imagery, architecture of satellite sensors to achieve higher spatial, spectral, and temporal resolution
- Outreach with and connections between the *public*, *industry*, *academia*, *private sector*, and *USG*
- Microplastics
  - Long term plan to use science based information to drive policy change
- Macroplastics
  - Standard practice to geotag fishing nets, and other large items that have the potential to become marine litter, like shipping containers
- Collaborate with studies that offer ground truth opportunities
- Advocate for federal resources to support satellite based detection of marine debris

THANK YOU

United States Contributions to Global Ocean Plastic Waste Meeting 3