



From emission to deposition:
measurement techniques for aerosol and microplastic
exchange processes in the atmospheric boundary layer.



Piotr Markuszewski
Institute of Oceanology, Polish Academy of Sciences

Atmospheric physics seminar,
Institute of Geophysics, University of Warsaw.
17.04.2026

Outline

- Emerging problem of microplastics
- Why we should study aerosol emission and deposition?
 - Long range transport issue
 - Microplastic global budget
- Findings and methods
 - How to sample emission and/or deposition?
- Our research:
 - Microplastics and air-sea interaction
 - Black Carbon as atmospheric anthropic tracer
- Chalanges



United Nations about microplastics:

- Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- Especially target 14.1:
By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.



Current Opinion in Green and Sustainable Chemistry

- <https://sdgs.un.org/goals>
- Walker, *Curr. Opin. Green Sustain. Chem.* (2021)

Definitely not enough...

Goal 1: Eliminate poverty

Negative impacts on ecosystems and the economy

Goal 2: Eliminate hunger.

The presence of MP in food and soil can limit food availability.

Goal 3: Health and Well-being, MP Ubiquity!

Goal 6: Drinking Water

MP in drinking water and wastewater!

Goal 7: Access to Clean Energy

Plastics production is unsustainable

Goal 9: Industry, Innovation, and Infrastructure

No closed-loop production processes.

Goal 10: Reduce inequality

Waste export and improper disposal

Goal 11: Sustainable Cities and Communities

Unsustainable waste management is crippling urban infrastructure.

Goal 12: Responsible Consumption and Production

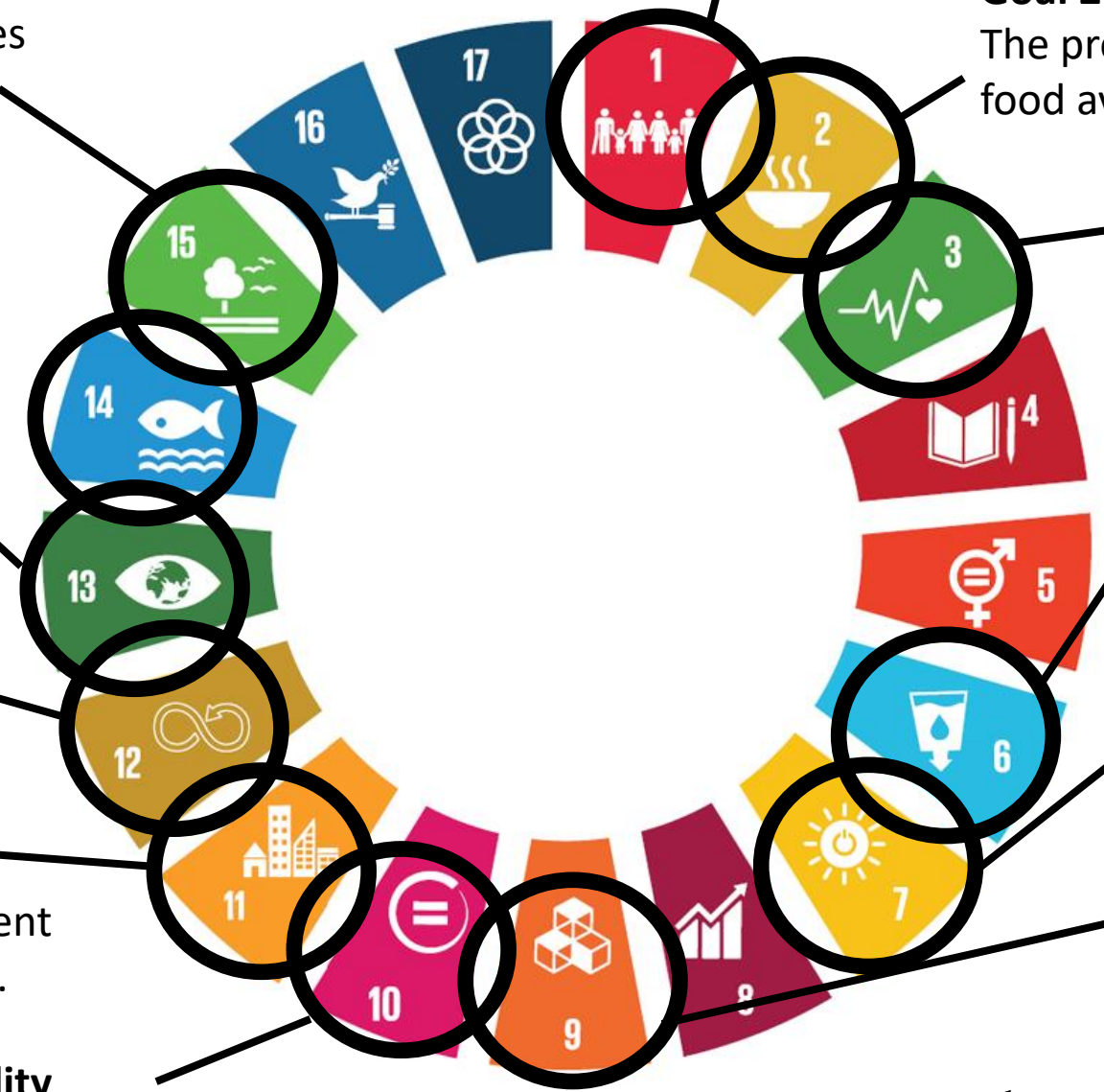
No sustainable plastic production

Goal 13: Climate Action,

Greenhouse gas emissions at every stage of production and disposal.

Goal 15: Life on Land

Poor waste management causes widespread land pollution.



- <https://sdgs.un.org/goals>
- Walker, *Curr. Opin. Green Sustain. Chem.* (2021)

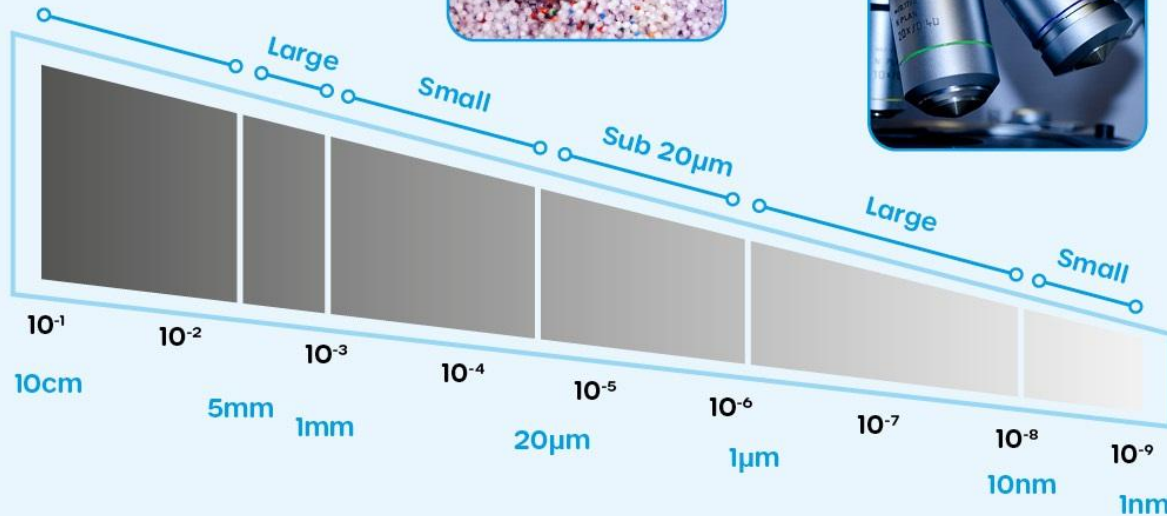
MACROPLASTICS



MICROPLASTICS



NANOPLASTICS



Visible with naked eye.

Can still be collected from the environment.

Still partially visible.

Advanced detection methods necessary.

Almost impossible to remove from the environment.

No longer visible.

Only detectable with very high effort.

Not removable from the environment.

The term ‘microplastics’ was first coined in 2004, initially referring to particles around 20 µm in size (Thompson et al., 2004)

Today, microplastics (MPs) are generally defined as < 5 mm, while nanoplastics (NPs) are < 1 µm.

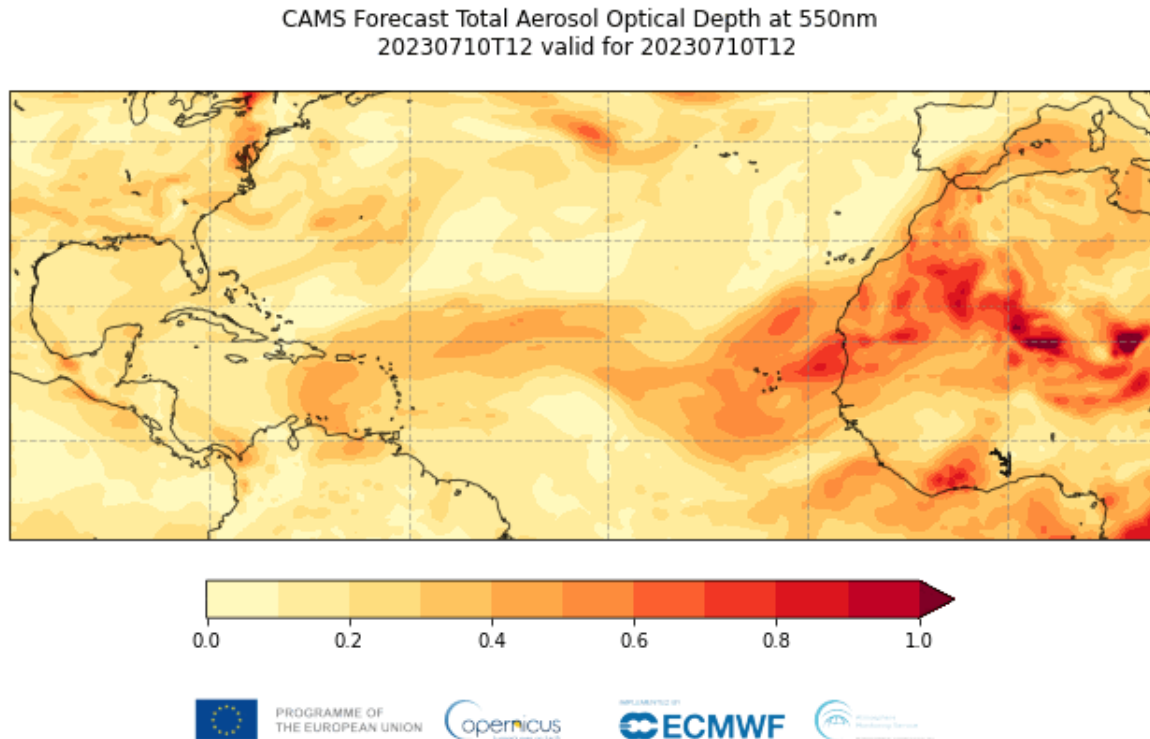
Compared to macroplastics (> 25 mm), (Boctor et al., 2025).

Unfortunately, this terminology conflicts with some of the adopted terminology. For example, in the nanomaterials field, nanoplastics are typically considered as 100 nm (Welden, N. A., & Lusher, A. 2020)

Why we should study aerosol emission and deposition?

The mysterious long-range transport of giant mineral dust particles

Van Der Does, et al., (2018). *Science advances*, 4(12).

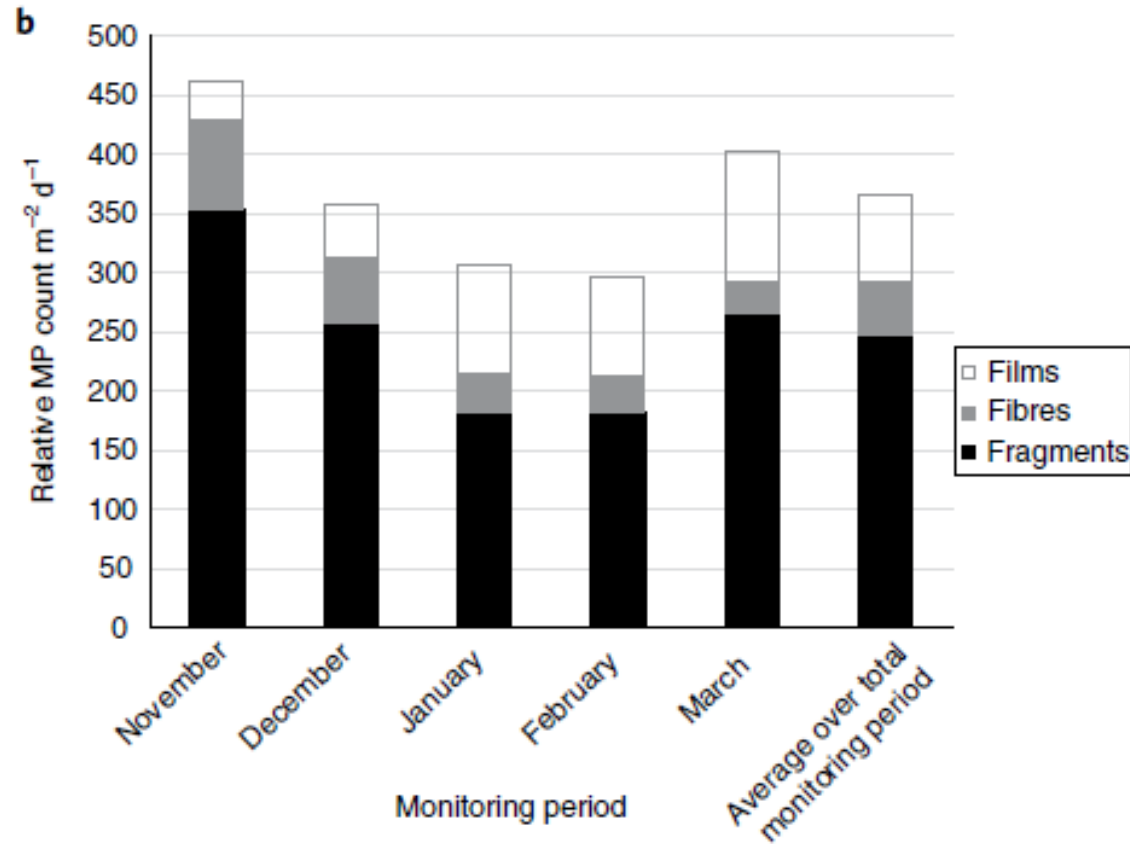


Animation of CAMS global 5-day total aerosol optical depth (AOD) at 550nm forecast initialized on 10 July at 12 UTC. Source: CAMS

- fast horizontal transport,
- turbulence,
- uplift in convective systems,
- electrical levitation

Why is it so important?

Long range atmospheric transport of microplastics...

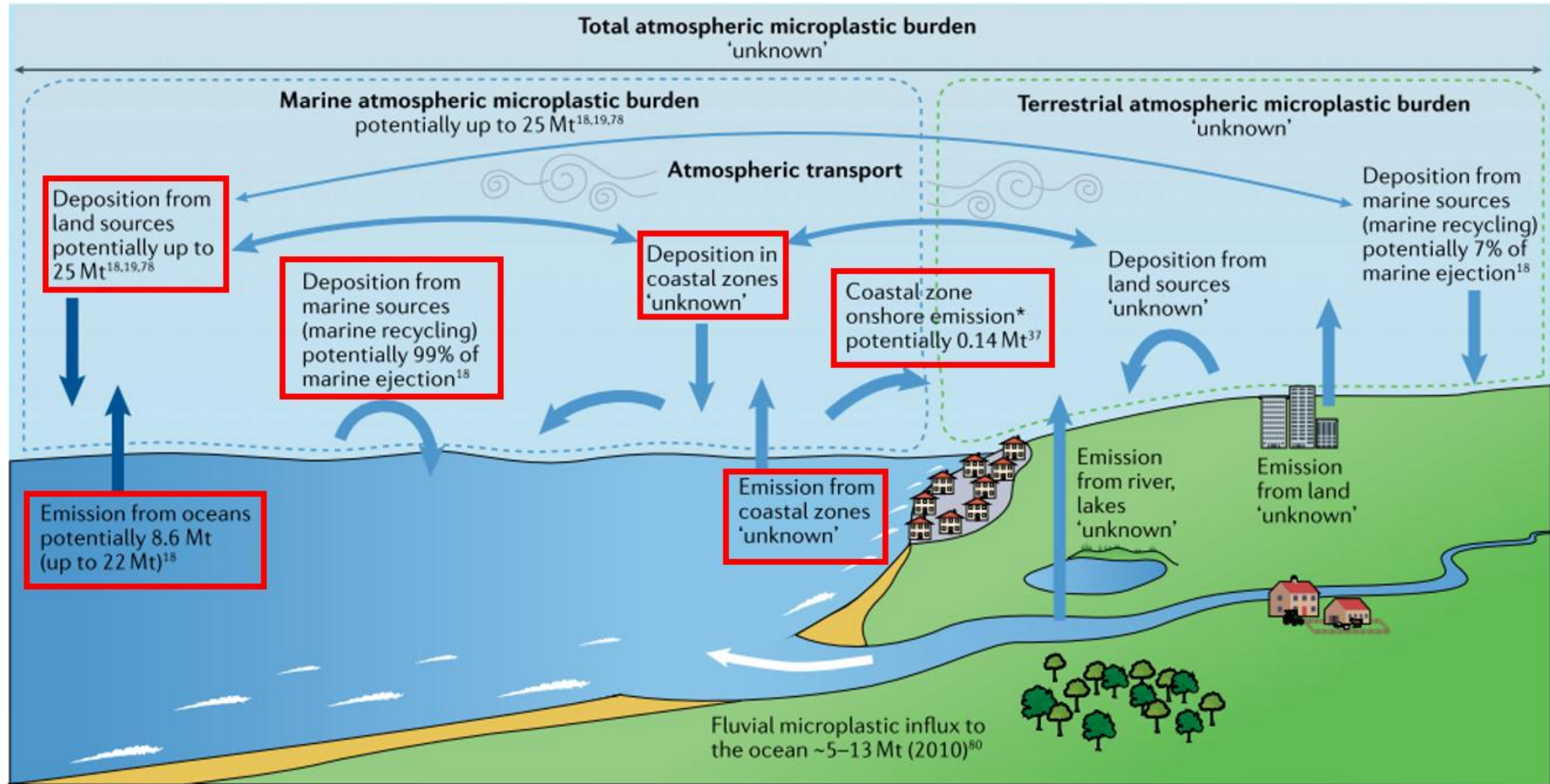


Microplastics in high mountains
(**French Pyrenees**)

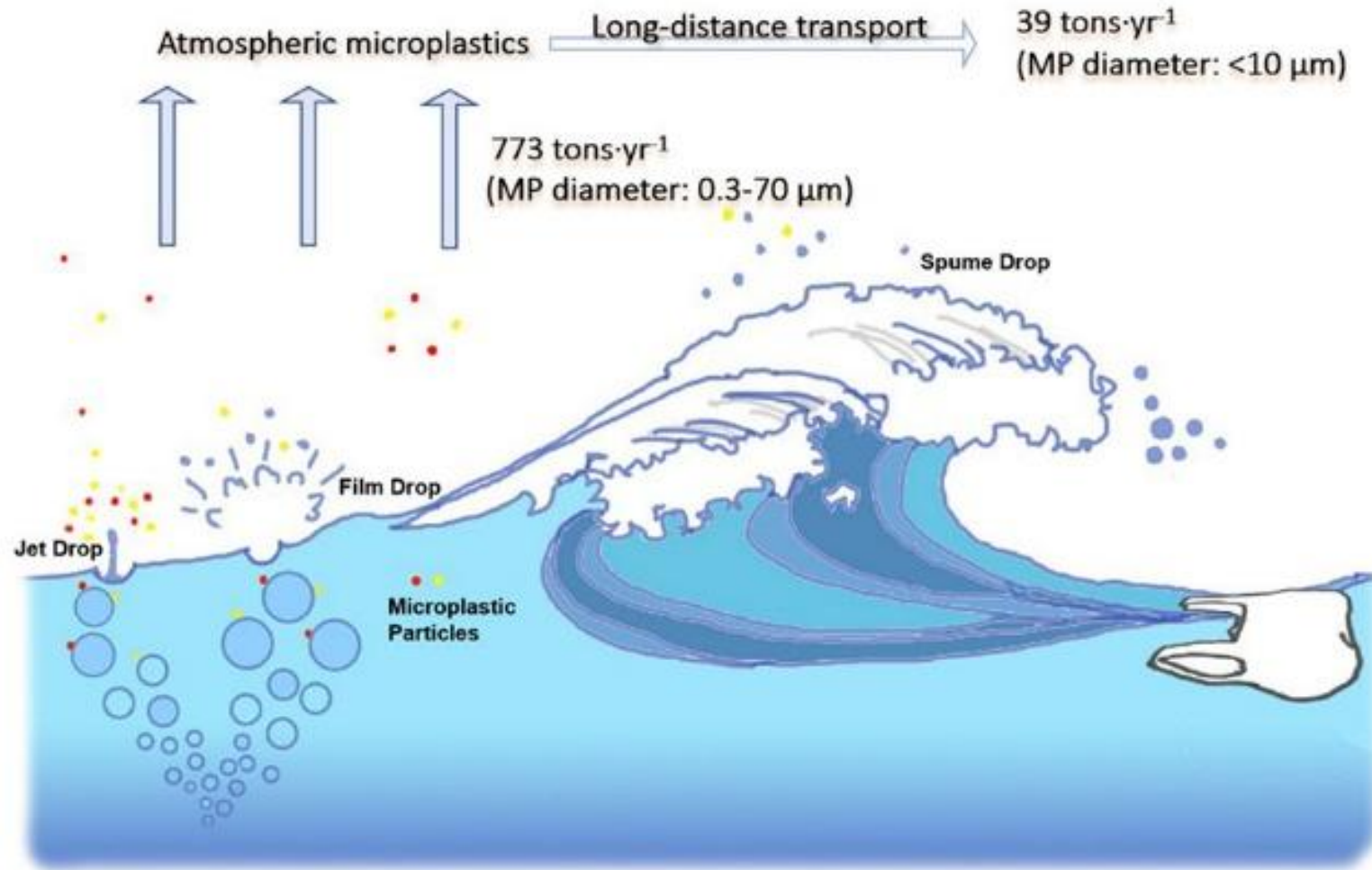
Atmospheric MP deposition captured in the collectors, MP occurrence

How about marine regions?

Atmospheric microplastic transport, potential annual flux, burdens and current knowledge gaps.

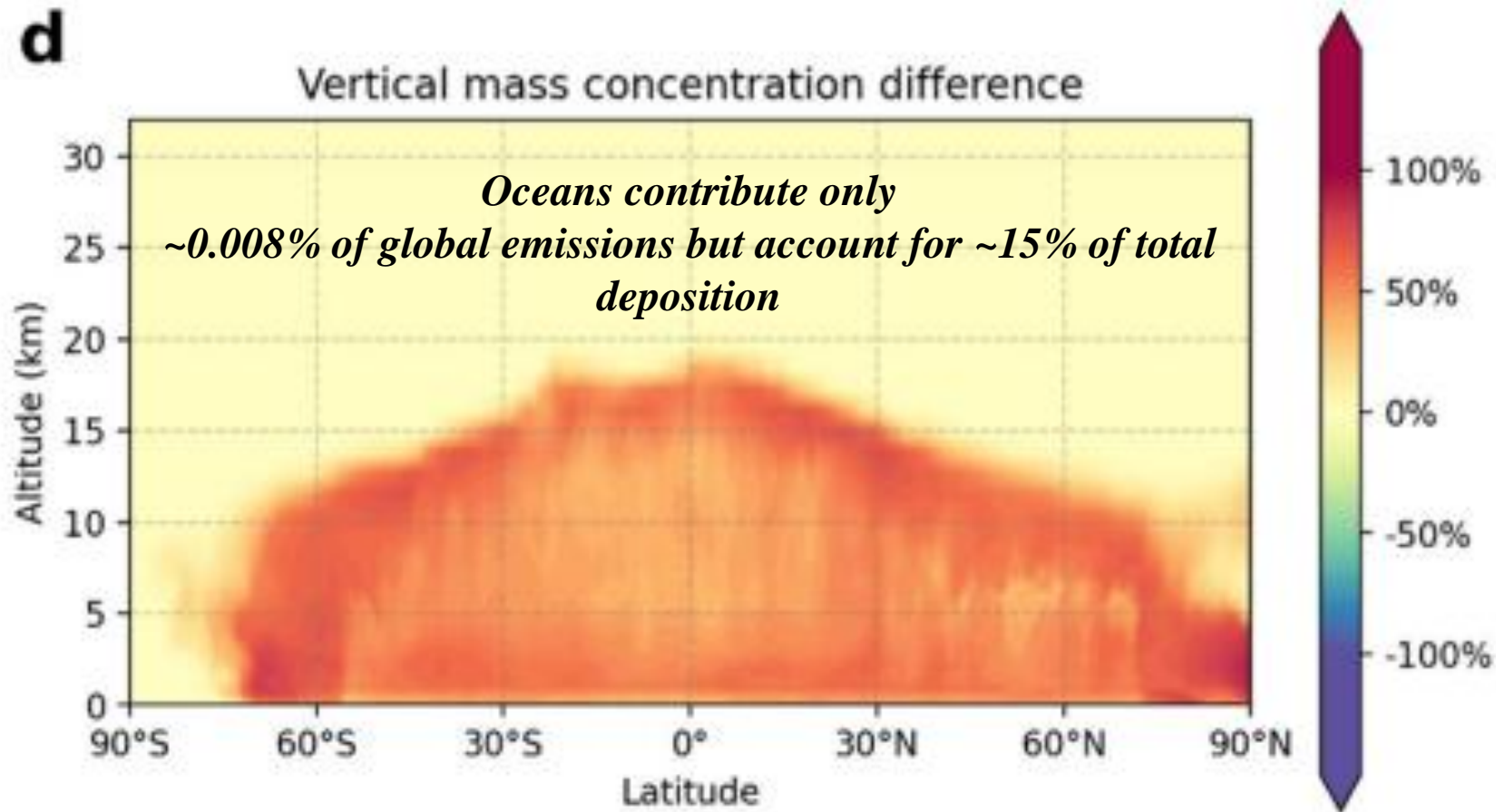


Challenge 1 – a weak source in comparison with anthropogenic



Our study strongly suggests that the oceans are unlikely to be a significant source of atmospheric MP relative to other anthropogenic sources of MP.

Challenge 2 – differences between fibers and spheres



Percentage difference in the mass concentrations for particles represented in the base versus the spheres case, The percentage difference is expressed as $(\text{base} - \text{spheres}) / \text{base}$.

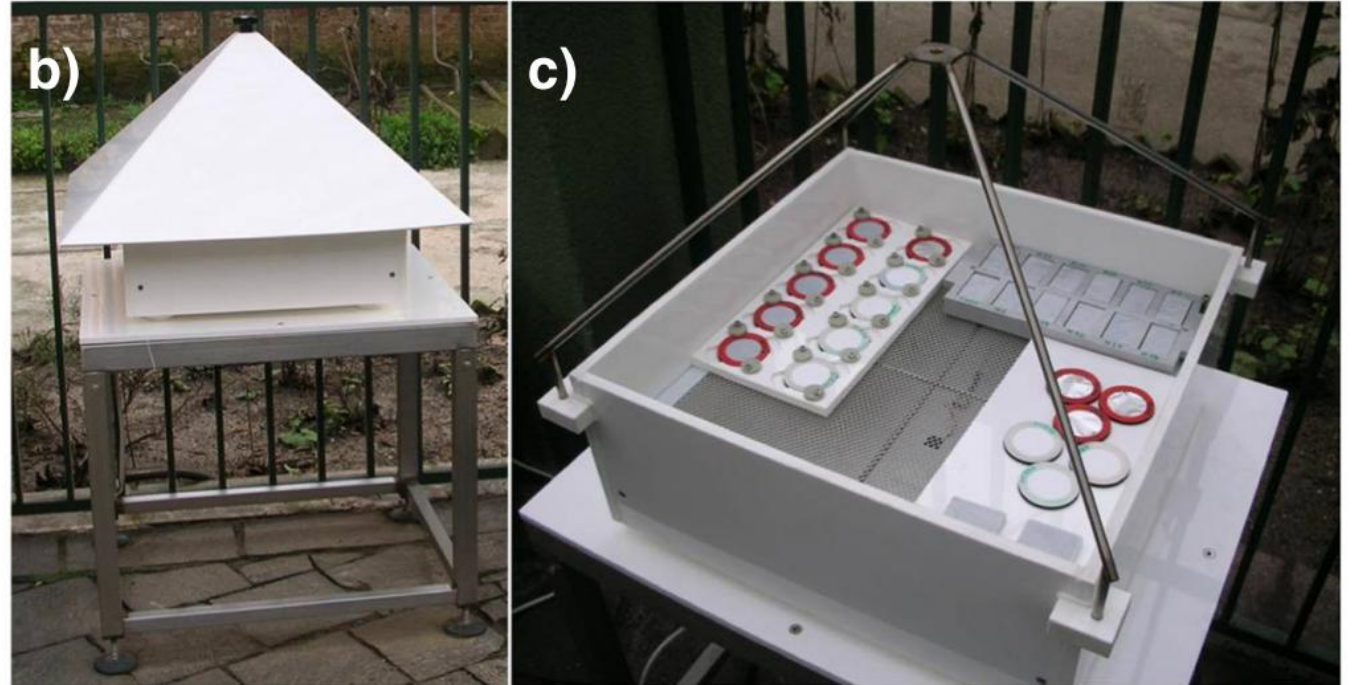
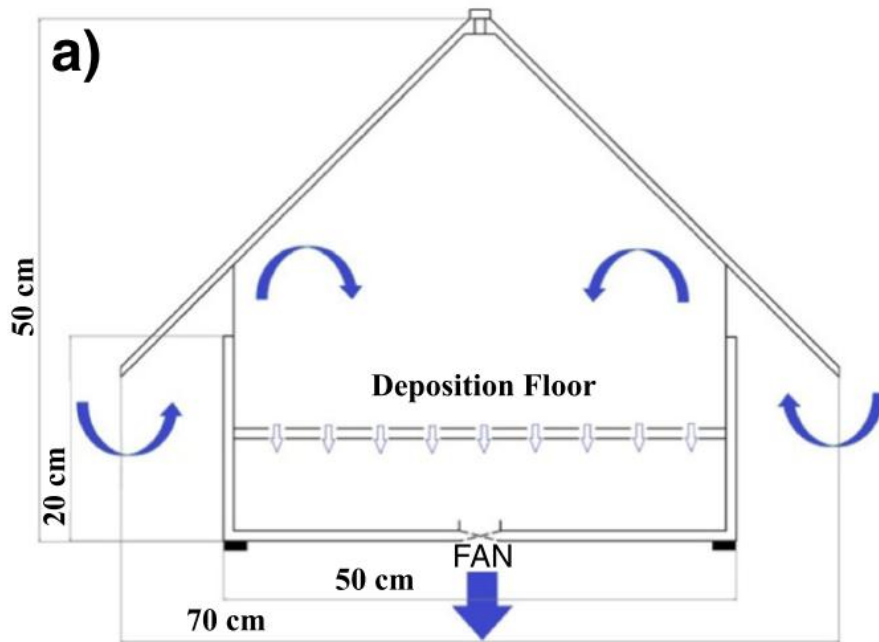
Findings and methods



How to sample emission and/or deposition?

How to sample emission and/or deposition?

Classic dry deposition method



Advantages

The primary appeal of passive sampling lies in its simplicity and cost-effectiveness:

- **No Power Requirement**
- **Cost-Effective**
- **Long-Term Integration:**
- **Zero Noise**
- **Minimal Maintenance**

Disadvantages

Despite their ease of use, passive samplers come with significant physical and analytical limitations:

- **Low Temporal Resolution**
- **Wind Sensitivity**
- **Particle Size Bias**
- **Complex Calibration**
- **Contamination and Interference**

Active sampling, sequential aspirators



Advantages:

The use of an active, automated system provides high-precision data that passive methods simply cannot match:

- **Higher Temporal Resolution**
- **Accurate Volumetric Quantification**
- **Size Selectivity**
- **Unattended Operation**
- **Reduced Sample Degradation**

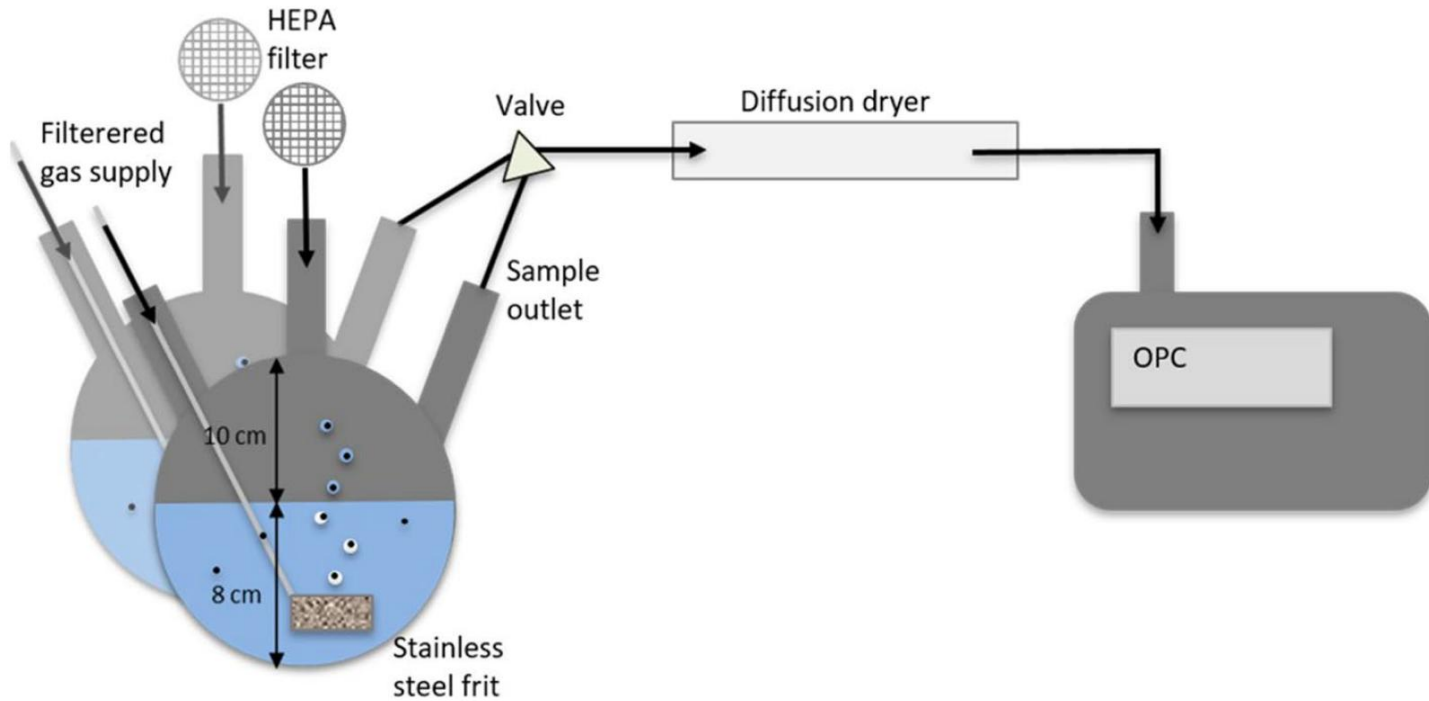
Disadvantages:

The complexity of these systems introduces logistical and financial hurdles:

- **High Initial and Operational Cost**
- **Power Dependency**
- **Noise Pollution**
- **Artifact Formation**

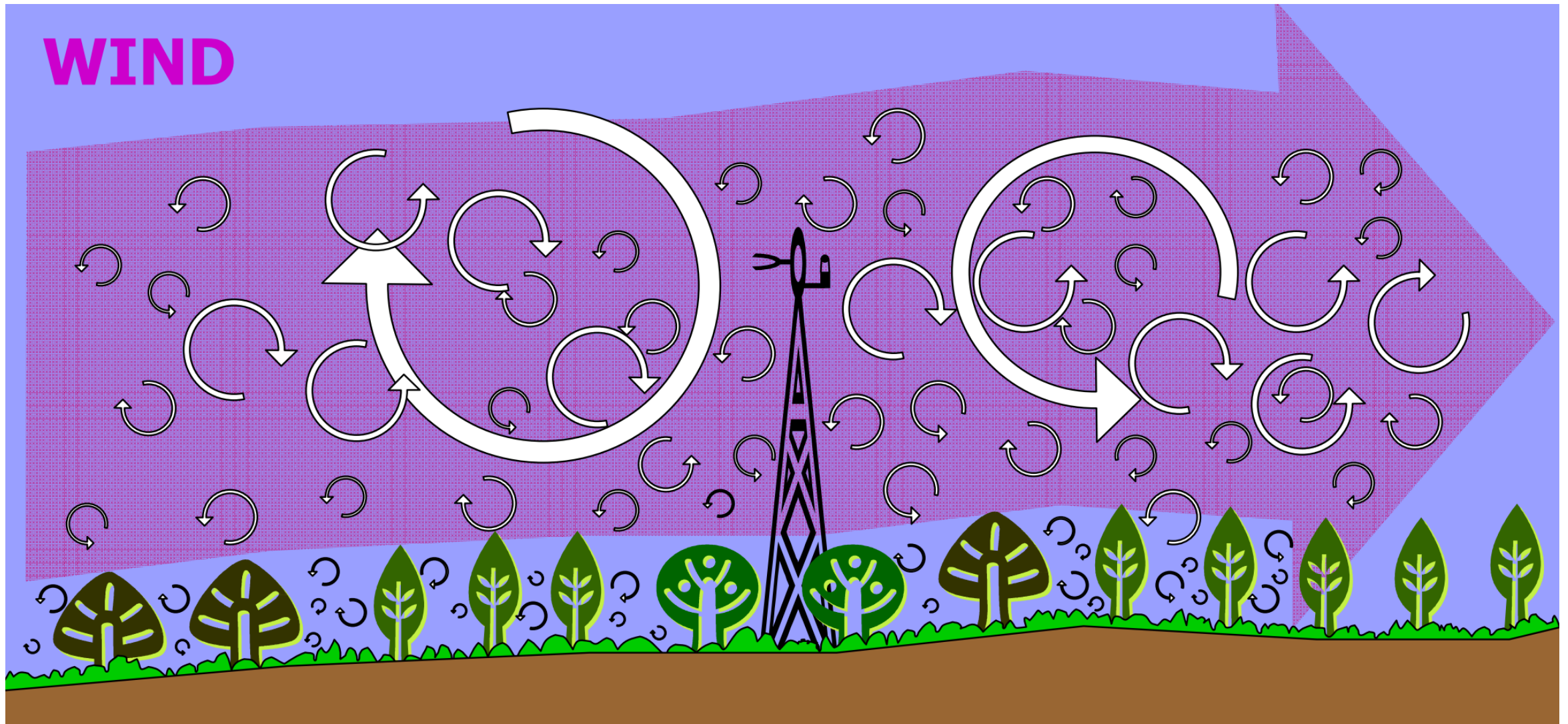
Aerosol aspirator DadoLab Gemini on board rv Oceania in Svalbard
(Longyearbyen, Norway)

Lab simulation – interfacial emission

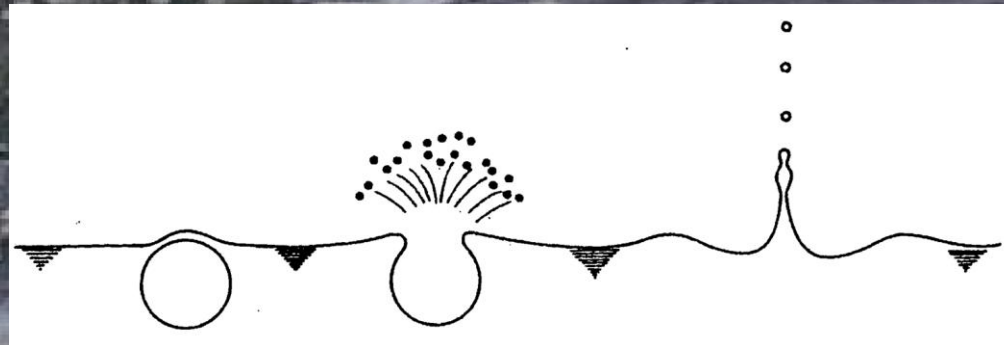


- Bubble bursting – film and jet drops
- Enrichment factor calculation
- ONLY POLYSTYRENE SPHERES!
- far from natural environment

Micrometeorology approach



Eddy Covariance



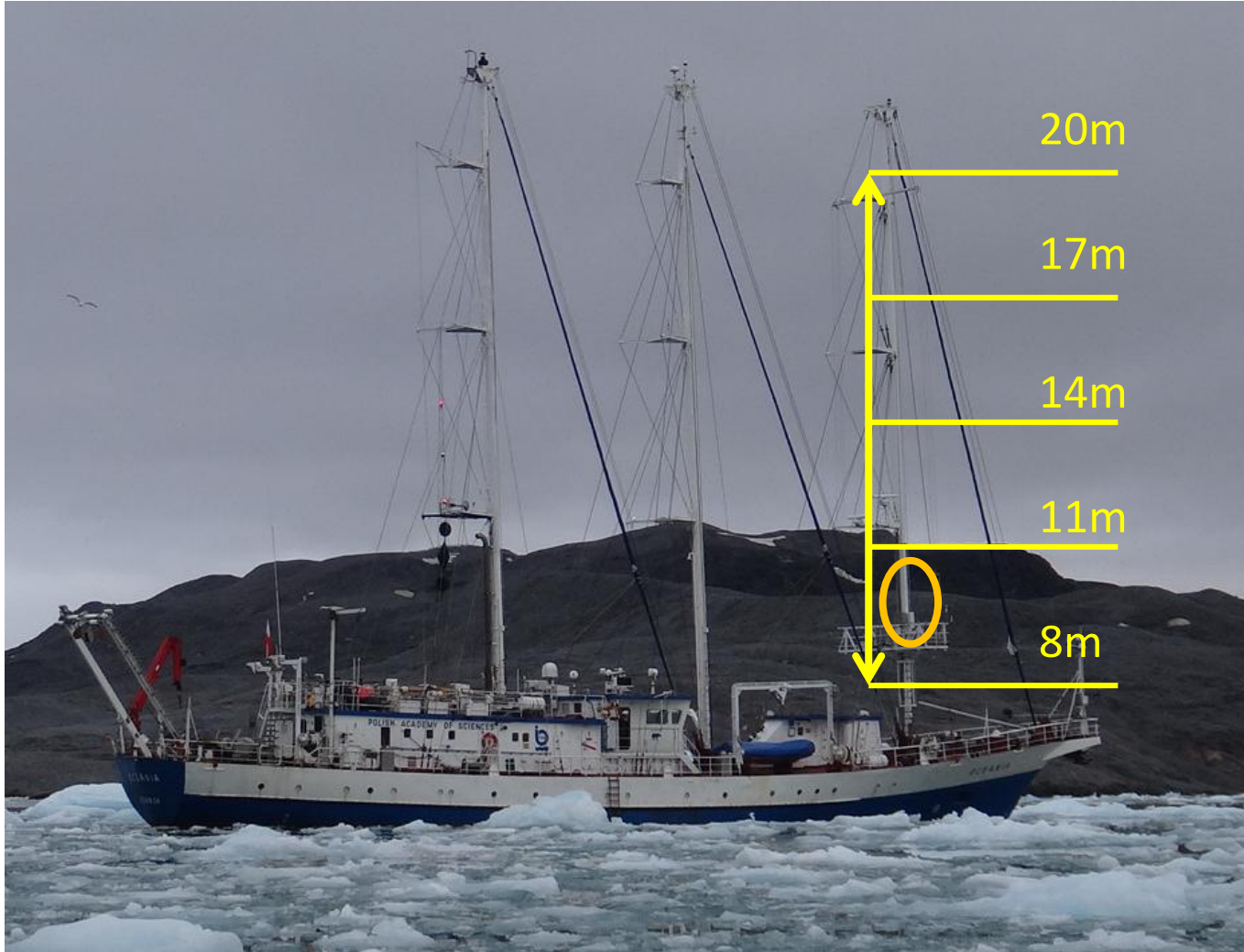
Primary Marine Aerosol Source

In the presence of a surface aerosol source the Eddy Covariance method “see” the sources as an upward flux. Each eddy’s upward draft will move up higher concentration, and vice versa. This results in a positive covariance = emission. Sinks cause a negative flux, downward. Dry deposition is always there: source must be > sink, true for sea spray, traffic emissions etc. Only local sources contribute to upward fluxes!

Nilsson et al., 2001, 2021
Zinke et al., 2024

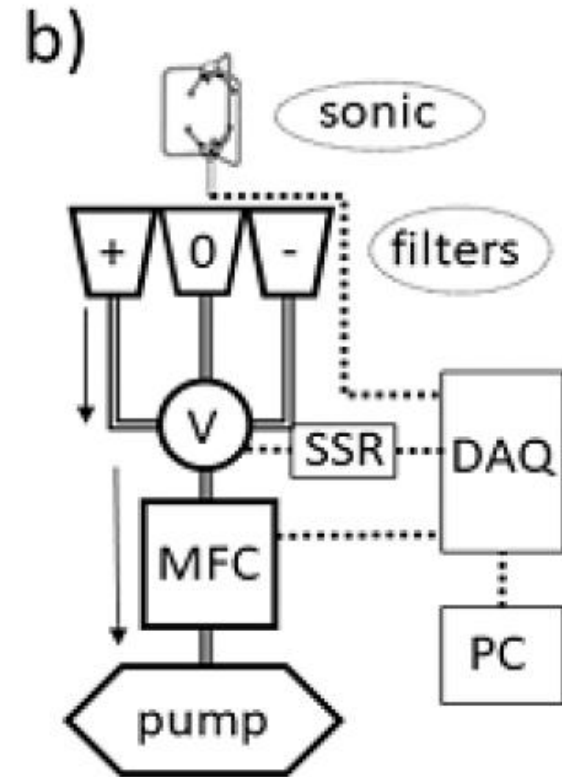
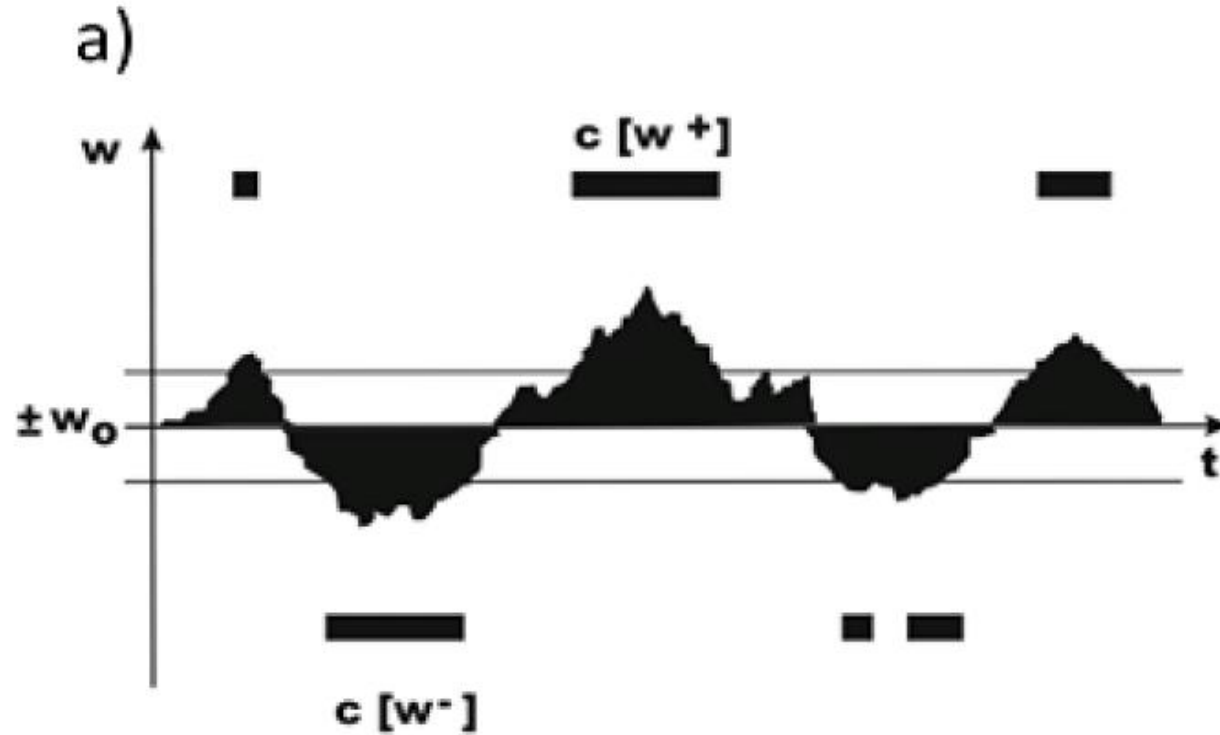
Aerosol gradients

$$\frac{dN}{d \log r_{80}}(z) = \left(\frac{-1}{\kappa u_*} \right) \left(\frac{dF}{d \log r_{80}} \right) \ln \left(\frac{z}{z_{ref}} \right) + \frac{dN}{d \log r_{80}}(z_{ref})$$



Petelski, *J. Aerosol Sci.* 2003
Markuszewski et al., *ACP*, 2024

Relaxed Eddy Accumulation



Foken et al., 1995
Gaman, A., et al., 2003

Our research



Friends and Partners:

Stockholm University:

E.D. Nilsson, R. Krejci, S. Haslet

From Milan University-Bicocca:

L. Ferrero, S. Andò, N. Losi,

E. Bolzacchini, L. Scibetta

From Gdańsk University:

P. Jutrzenka-Trzebiatowska, A. Zaleska-Medynska

From Gdańsk University of Technology

M. Zawadzki, K. Stawiarz, M. Śmiszek

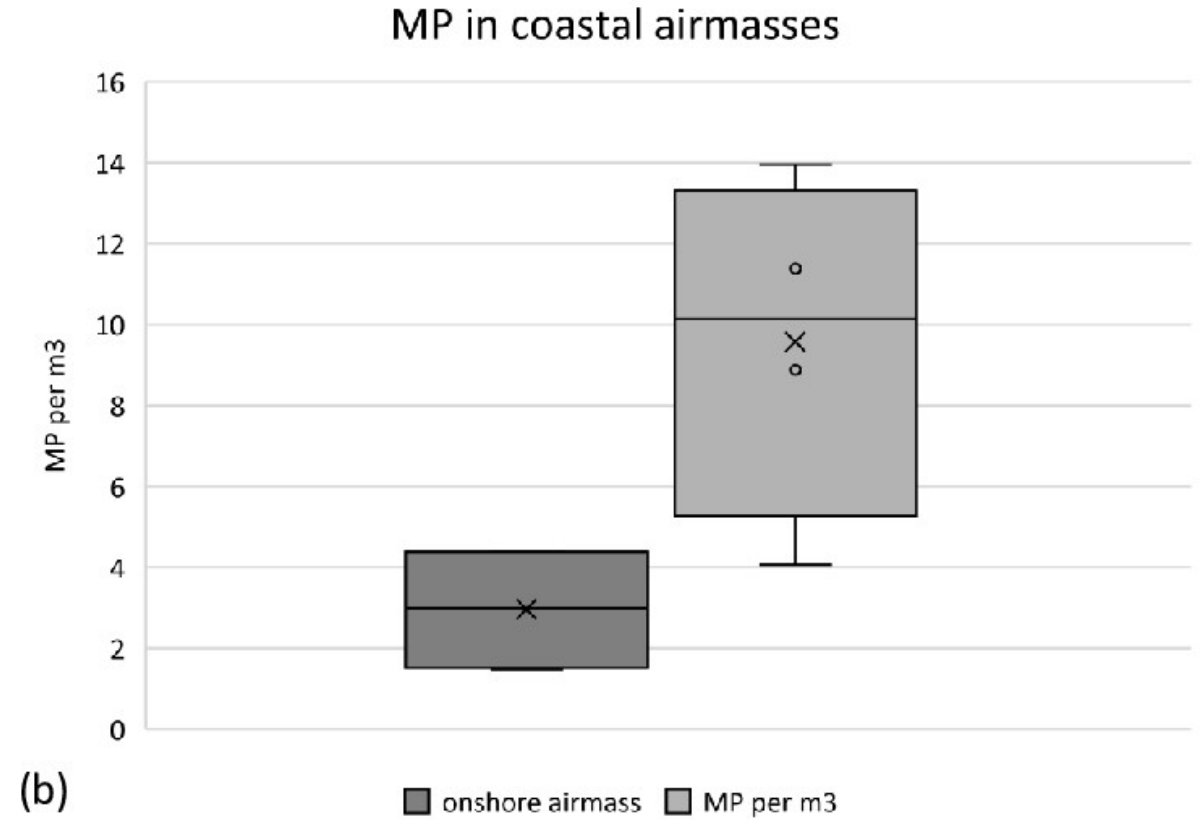
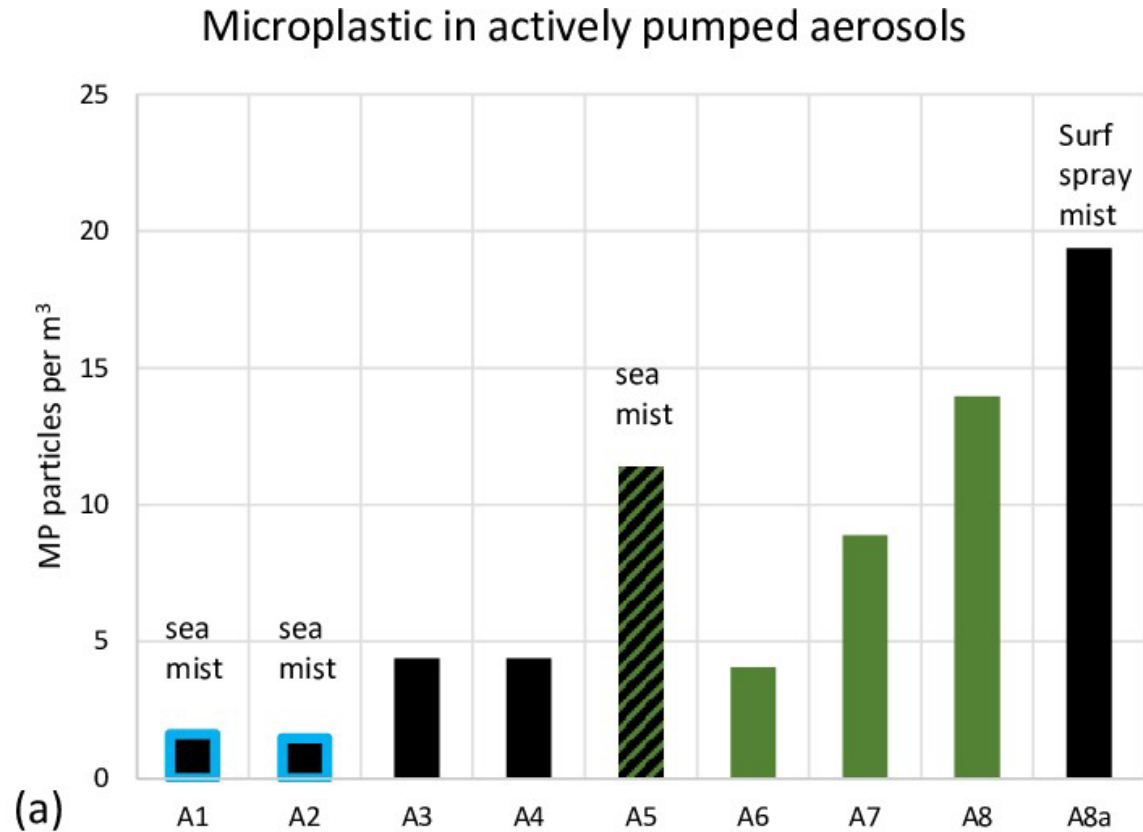
From Warsaw University:

K. Markowicz, A. Dąbrowska

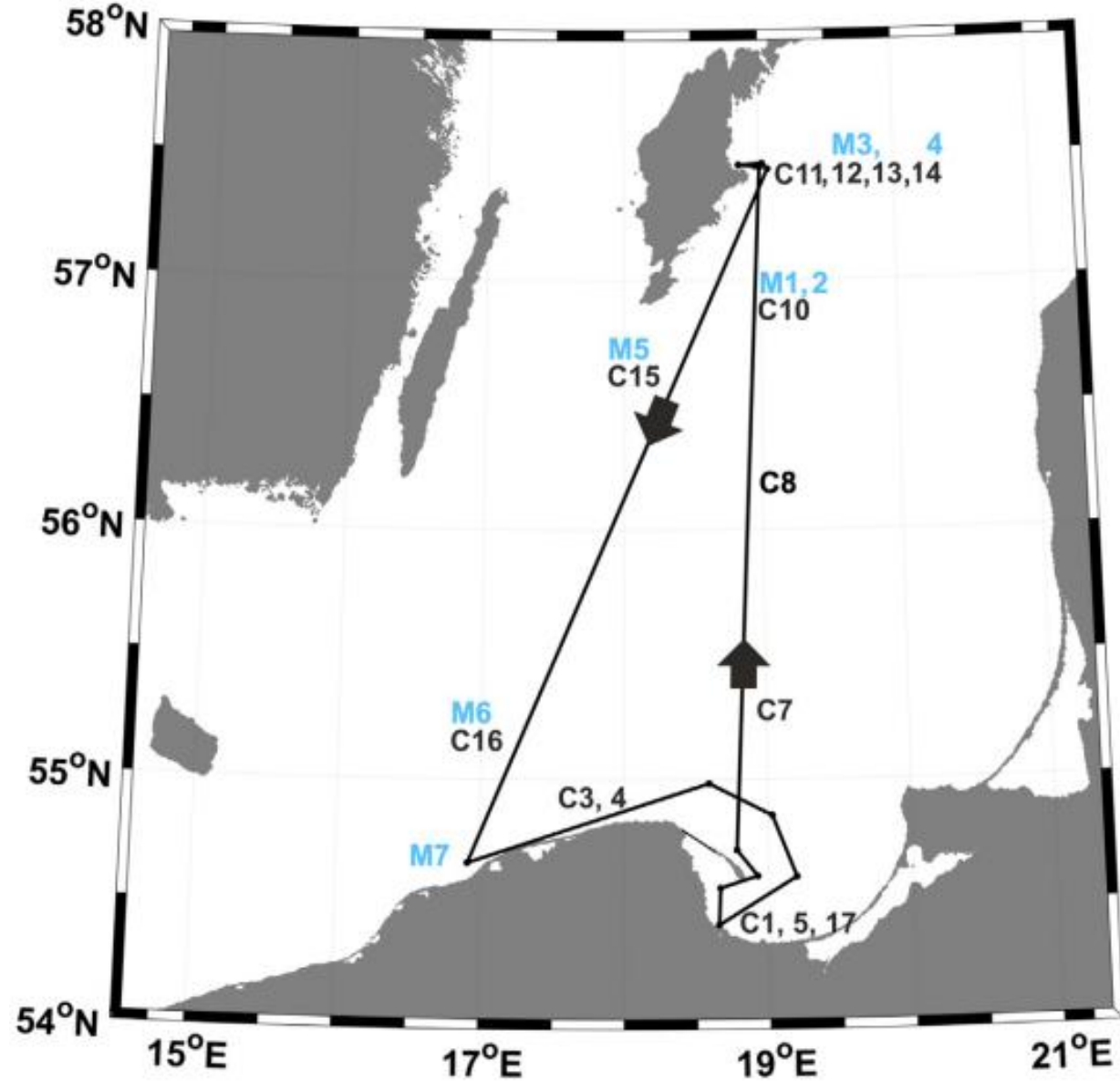
From IOPAS

M. Mazurkiewicz, V. Drozdowska, P. Makuch.

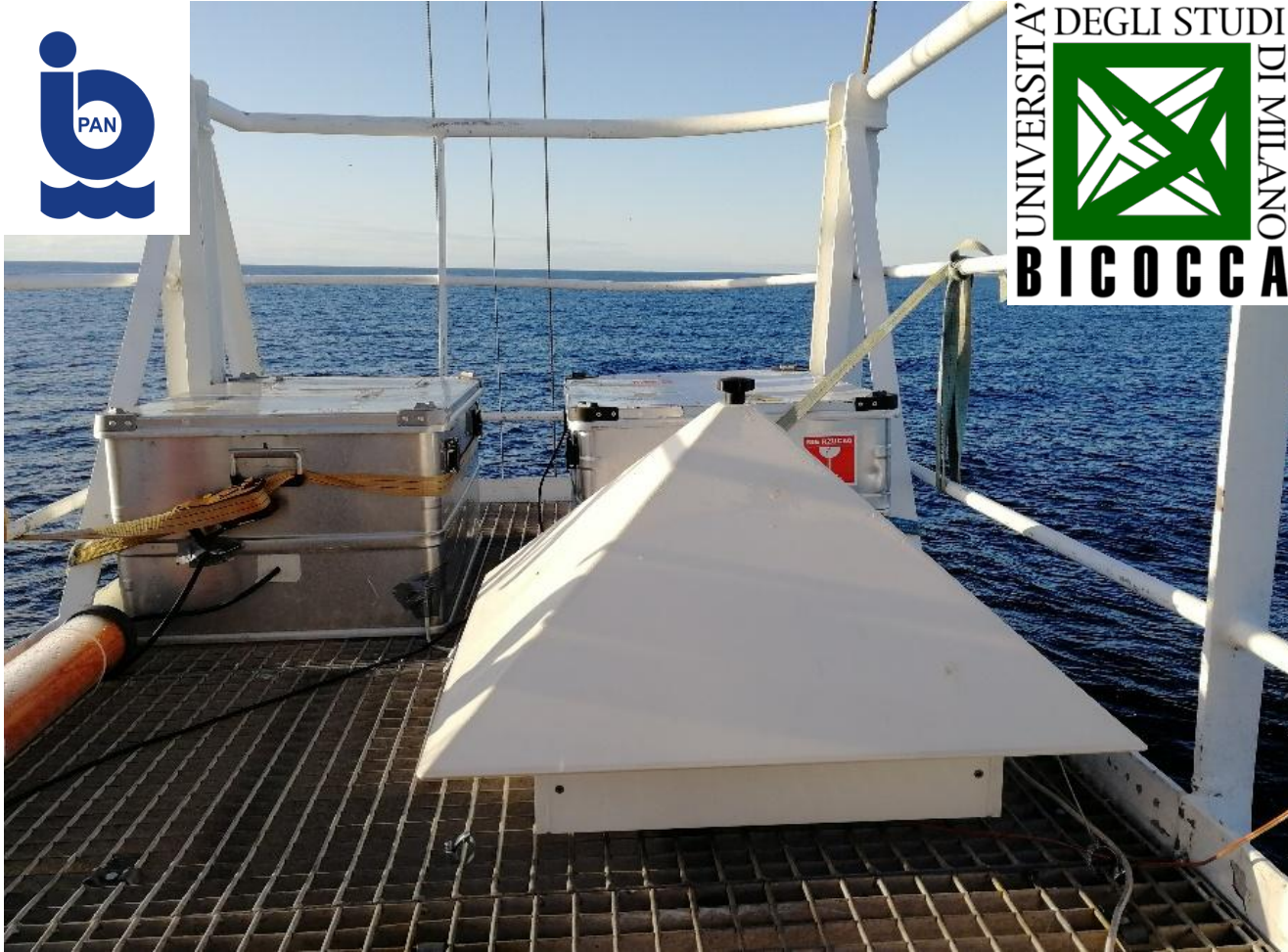
The first environmental evidence..



Research cruise, 16-31 October 2019



Measurements, atmosphere



r/v Oceania



Östergarnsholm Station

Additional measurements:

- LAS - TSI® model 3340 Range: $d=\{0,09-7 \mu\text{m}\}$,
- OPC-N3 $d=\{0.3-16 \mu\text{m}\}$,
- CPC TSI 3310 + (Eddy Covariance on the island),
- Weather probe Vaisala WXT536,
- LI-7500A + GILL® WindMaster+ IMU,
- Aethalometer 2x (AE-33 i AE-31, Magee Scientific),
- CTD, Sea-Bird SBE 19 plus.



Measurements, water



HydroBios 70x40x260 cm³

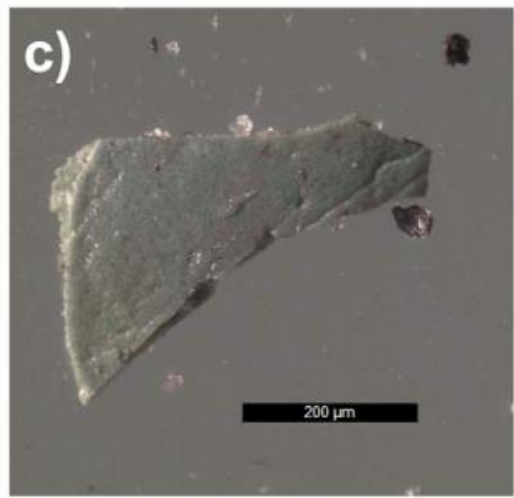
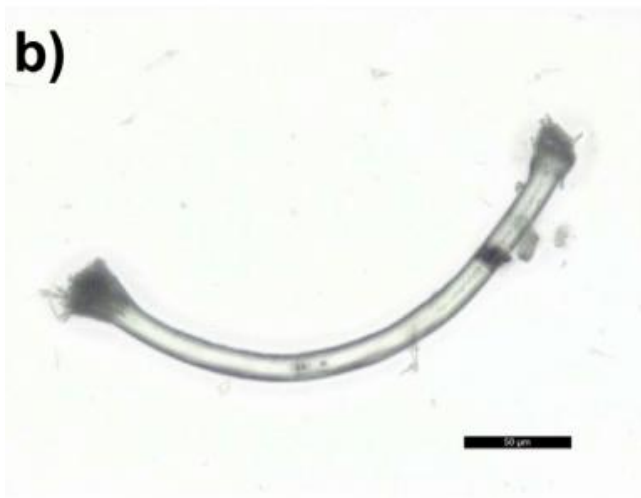
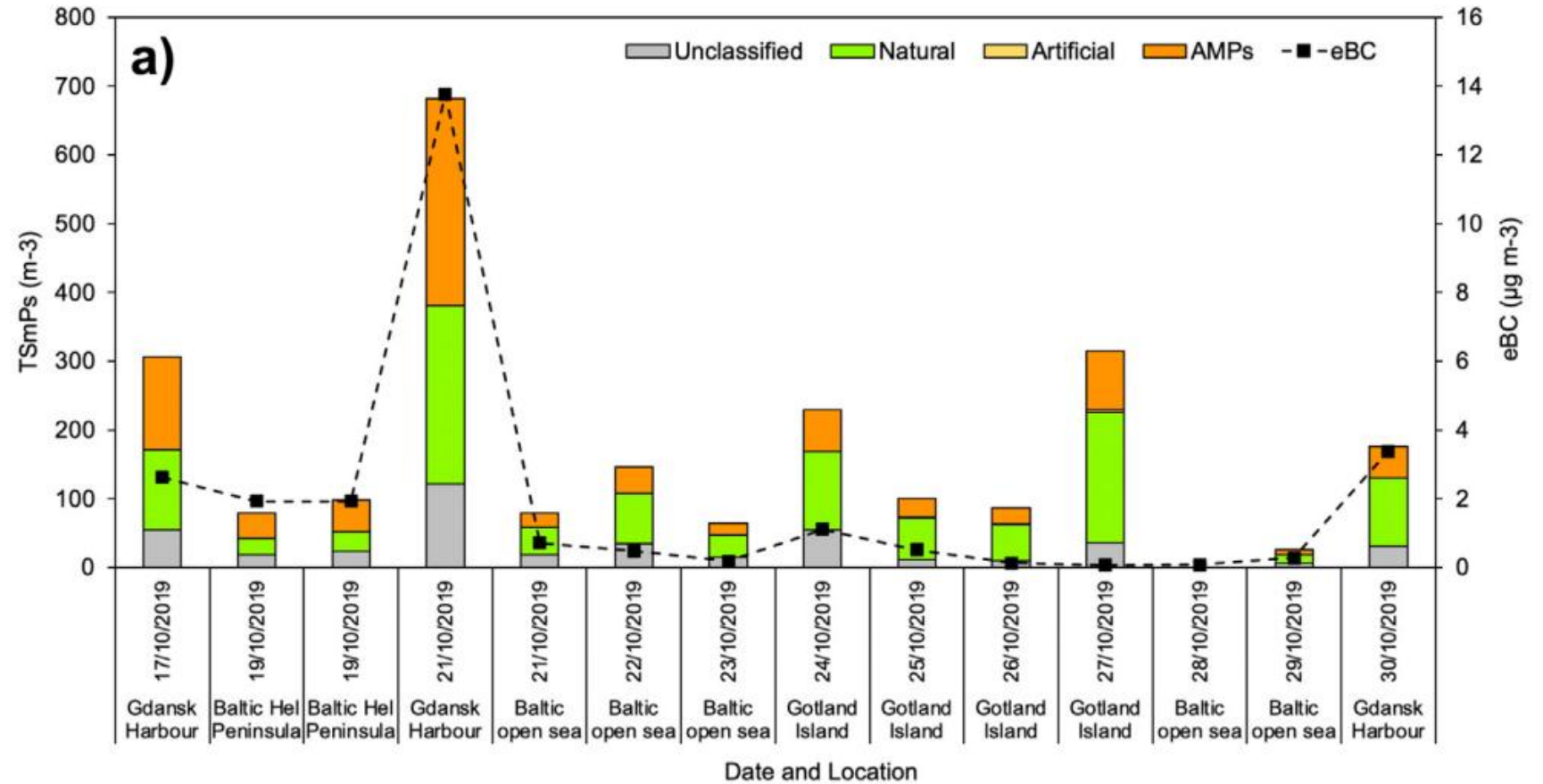
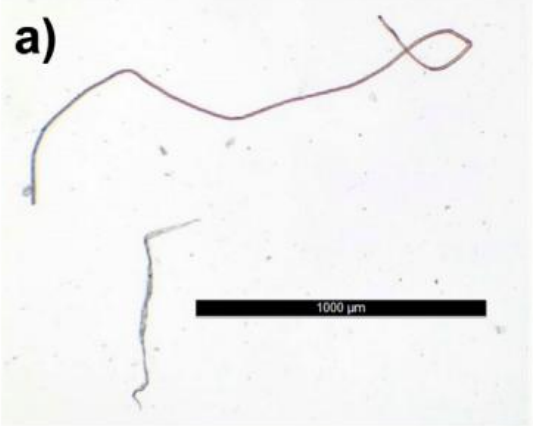
Mesh size 300 μm

Kukliński i in., *Mar. Pollut. Bull.* (2018)

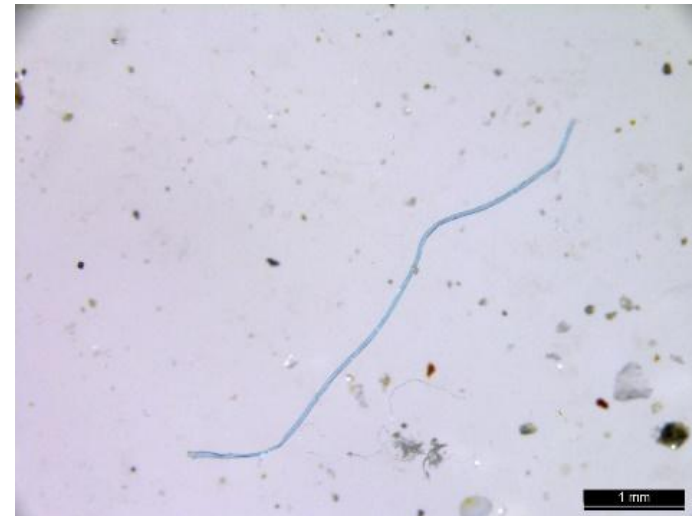
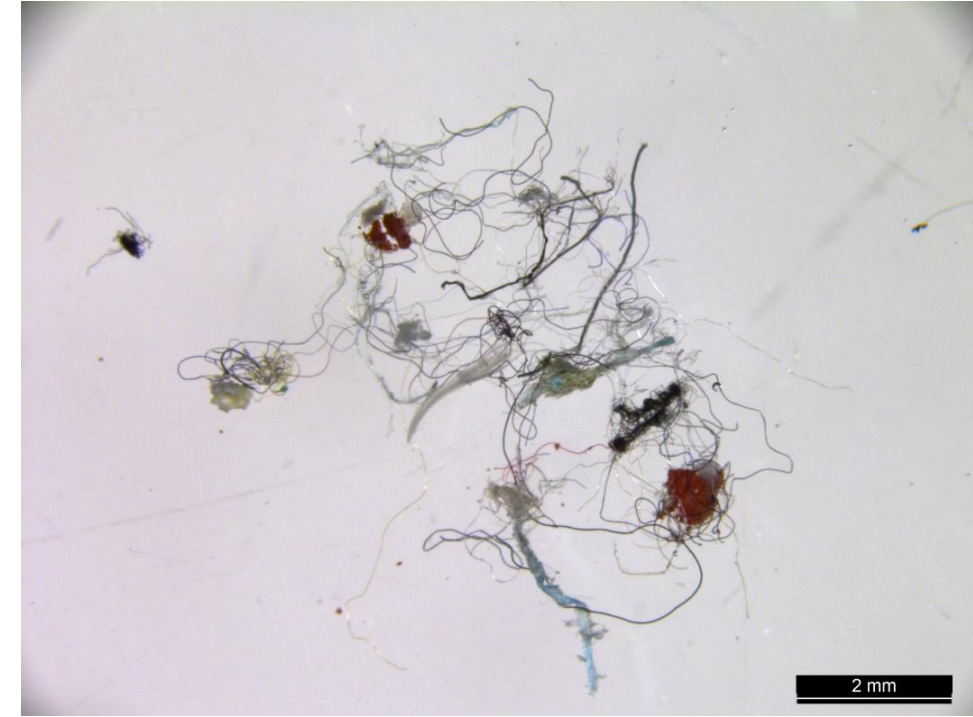
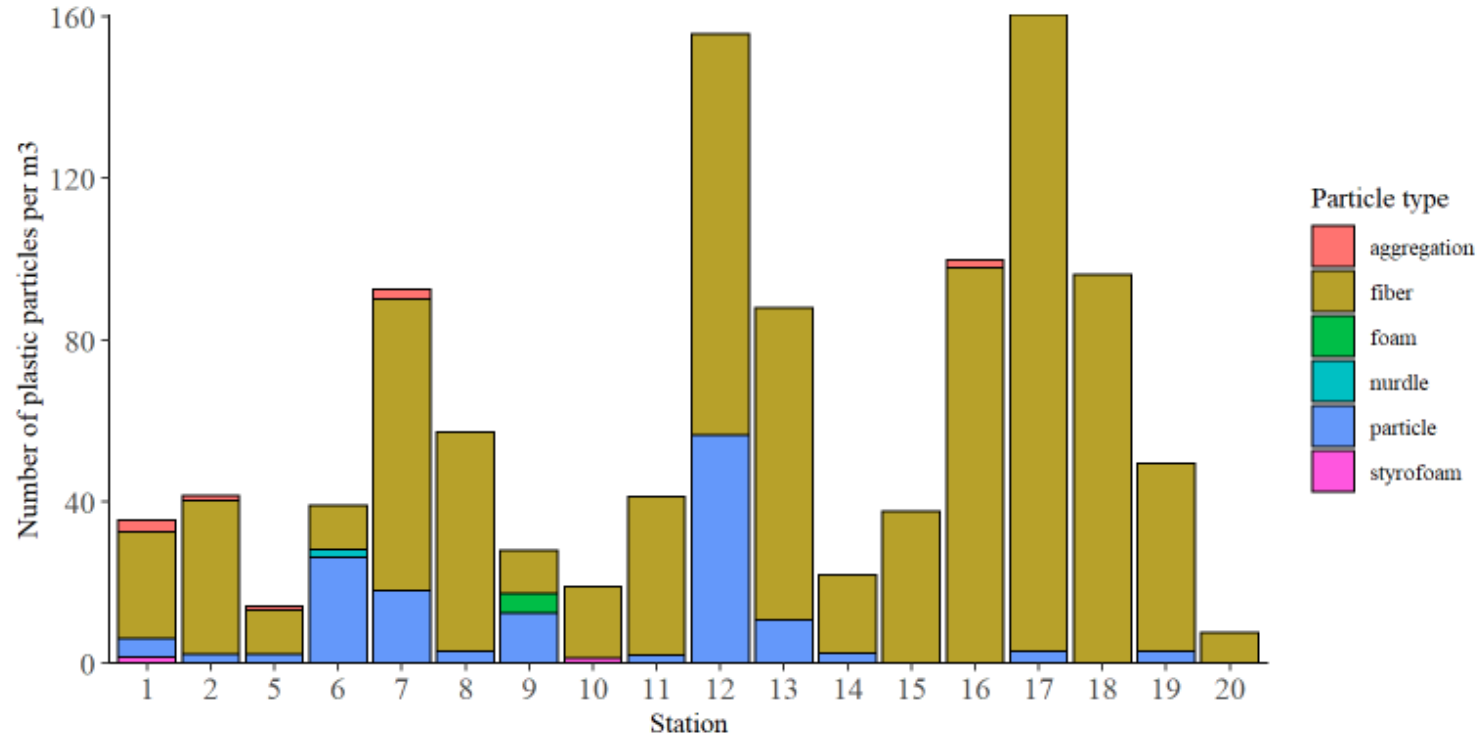
Results



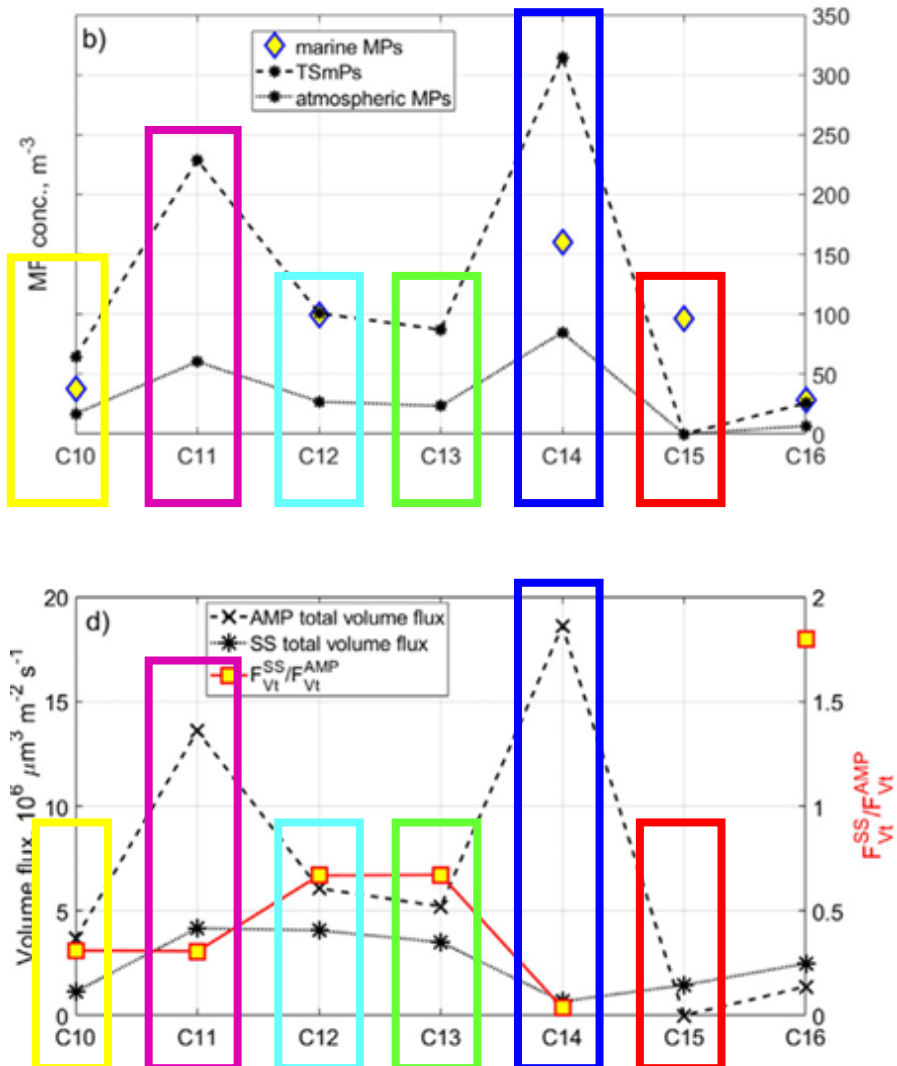
Air



Water

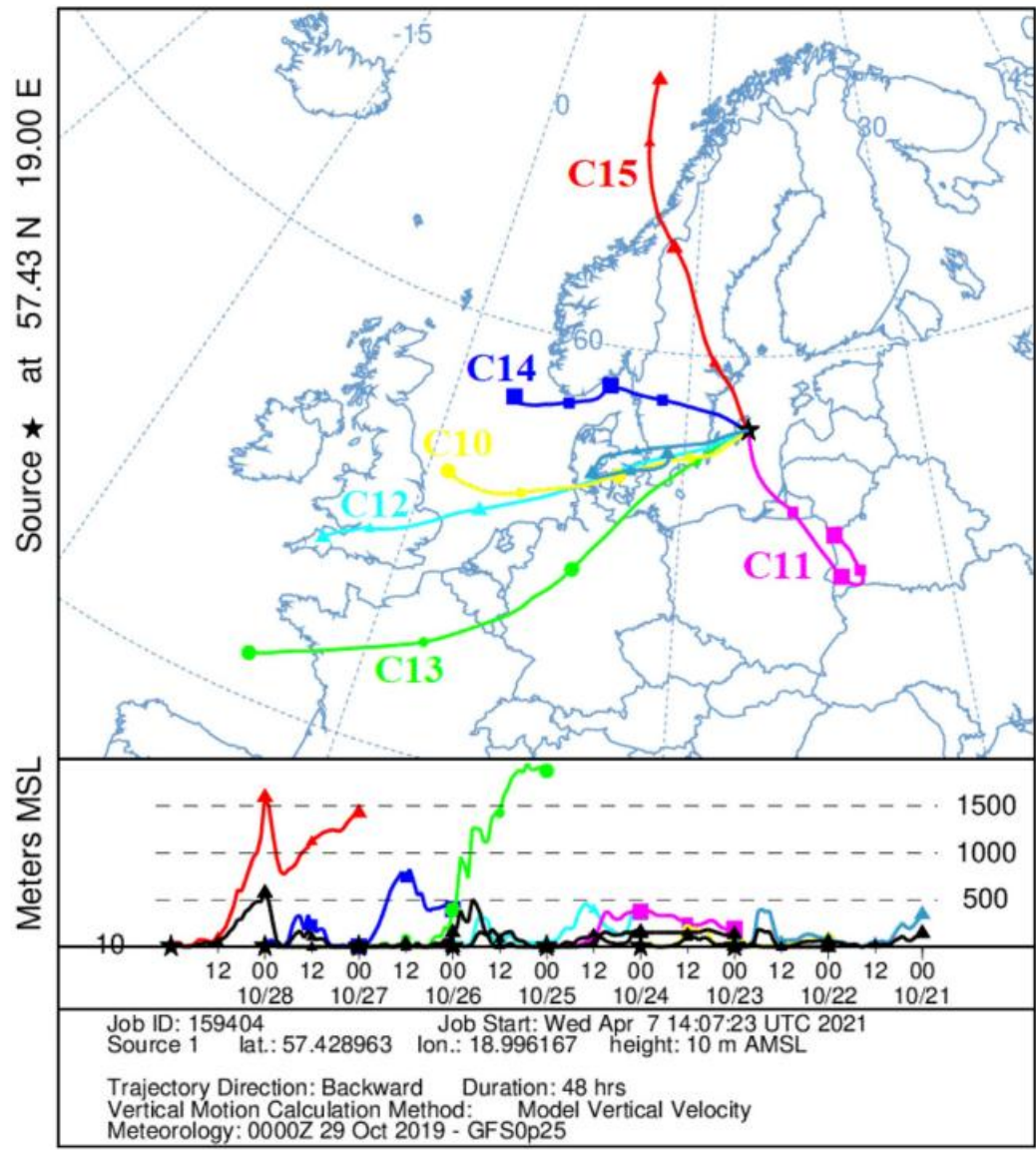


Time serie near Gotland



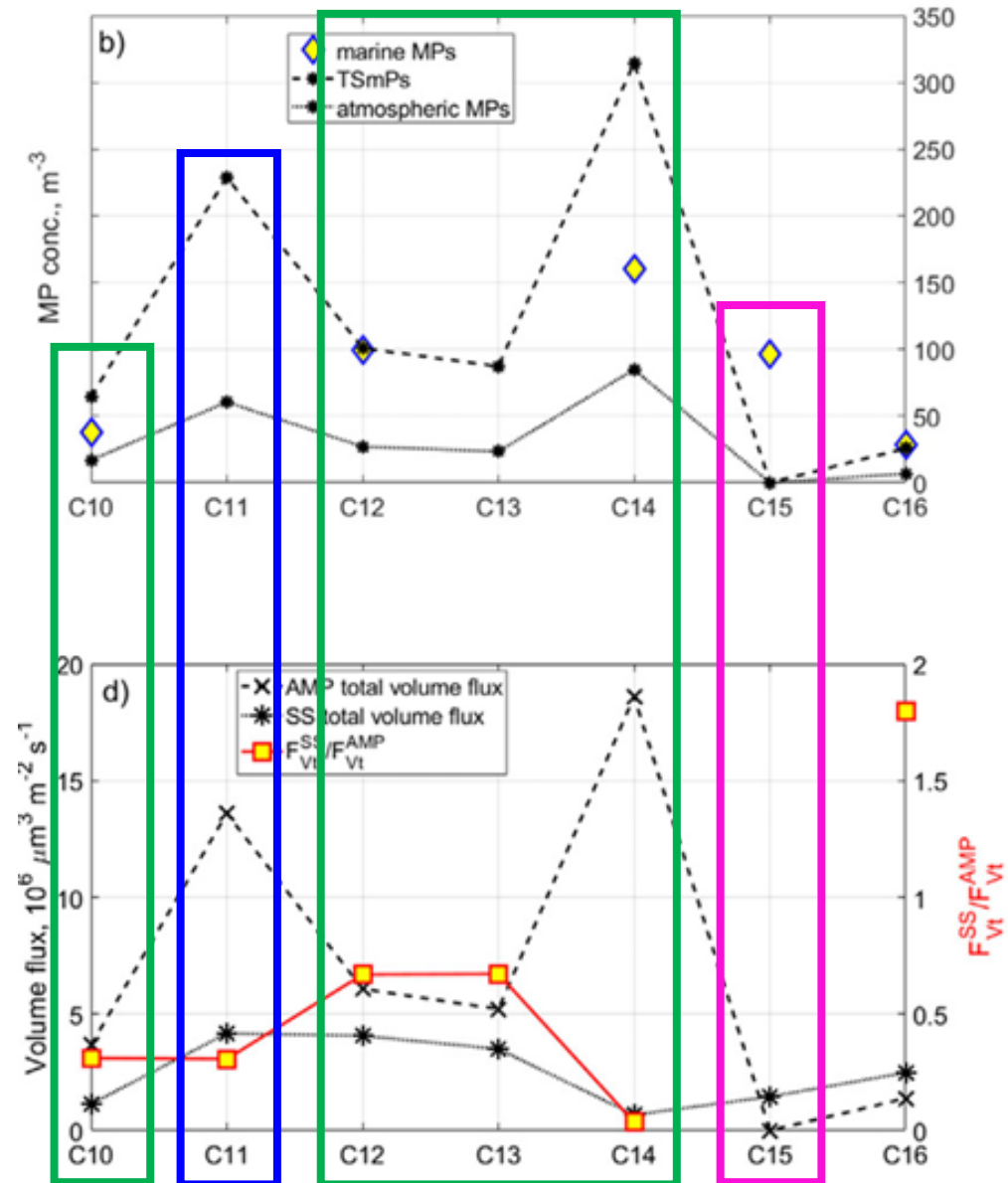
MP – mikroplastic,
 TSPs – total suspended microparticles,
 AMP – airborne MP,
 SS – sea spray emission.

NOAA HYSPLIT MODEL
 Backward trajectories ending at 0000 UTC 29 Oct 19
 GFSQ Meteorological Data



$$\tau[\text{h}] = \frac{H_{PBL}}{v_d(D_p)}$$

τ – turnover time, Nisson and Rannik, 2001,
 H_{PBL} – boundary layer height,
 v_d – deposition velocity



Sample	Time over the sea, h	Boundary layer height, m	Turnover time, h			Closest big agglomeration		
			$D_p = 9 \mu\text{m}$,	$D_p = 45 \mu\text{m}$,	$D_p = 90 \mu\text{m}$	City	Distance, km	Transport time, h
C10	3	341	36	2.5	0.4	Kalmar	180	10
C11	9	258	27	1.1	0.3	Kaliningrad	320	10
C12	2	844	90	3.6	0.9	Kalmar	180	6
C13	4	283	30	1.2	0.3	Kalmar	180	12
C14	3	727	77	3.1	0.8	Visby	40	2
C15	4	738	79	3.2	0.8	Stockholm	220	9

C10, C12, C13, C14 – land air mass advection,

C15 – wet deposition (rain) + Arctic air mass flow

C11 – long range AMP transport: deposition + reemission

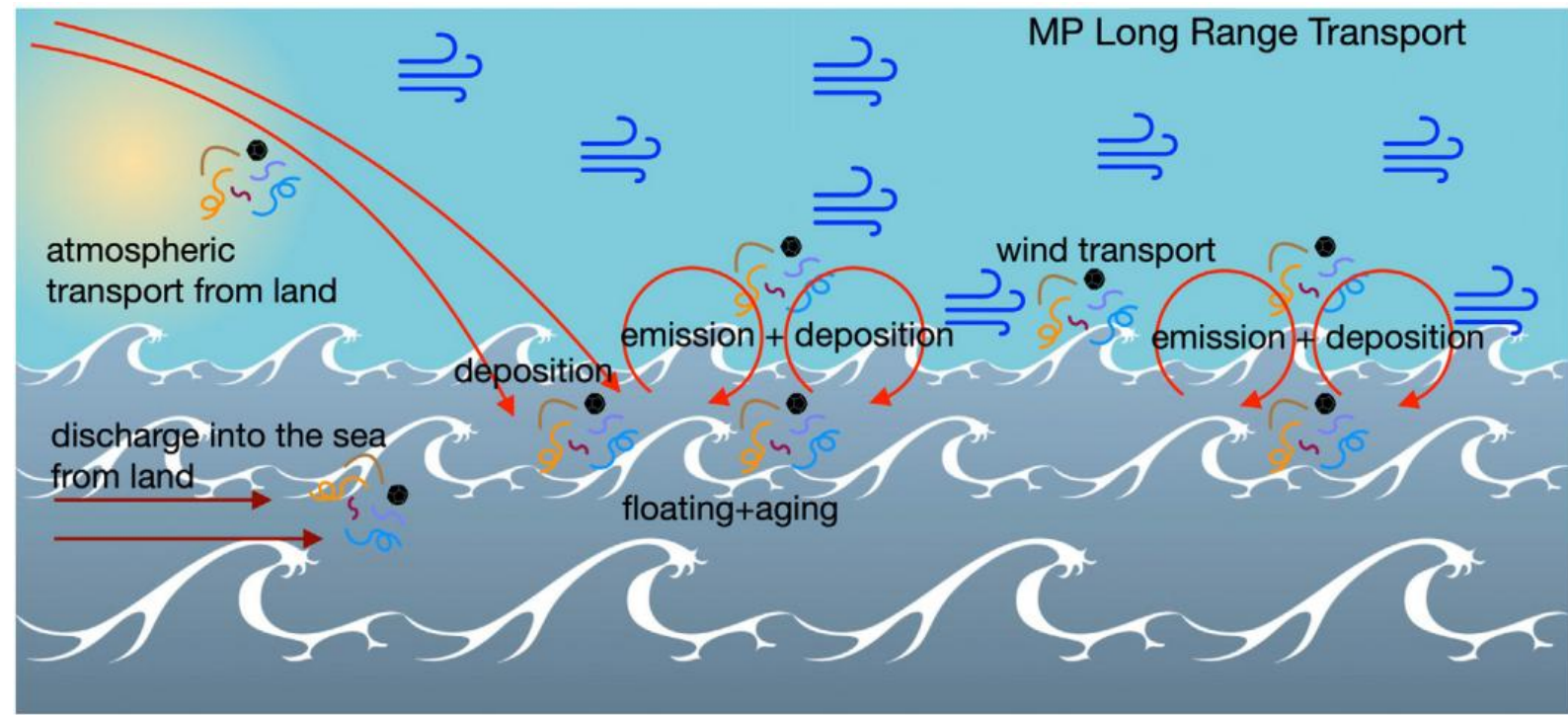
Results

Airborne microplastics:

- Gdańsk harbour: $161 \pm 75 \text{ m}^{-3}$,
- Baltic Proper: $24 \pm 9 \text{ m}^{-3}$,
- Gotland region $45 \pm 20 \text{ m}^{-3}$,

The measured values agree in order of magnitude with the MP in water $79 \pm 18 \text{ m}^{-3}$.

Moreover, the composition of MP (PE, PET, PU, PA, PS and PC) was similar (except for PC).



1. High AMP concentrations are caused by advection from urban areas (especially smaller filaments).
2. The presence of larger fibers in the atmosphere can be explained by the contribution of aerosol re-emission from the sea.
3. This process enables long-distance transport of AMP.

PE – polyethylene,
PET – polyethylene terephthalate,
PU – polyurethane,
PA – polyamide,
PS – polystyrene,
PC – polycarbonate.

Black Carbon as atmospheric anthropic tracer in the Indian Ocean region



Sampling area



Maldives Climate Observatory Hannimadoo (MCOH)

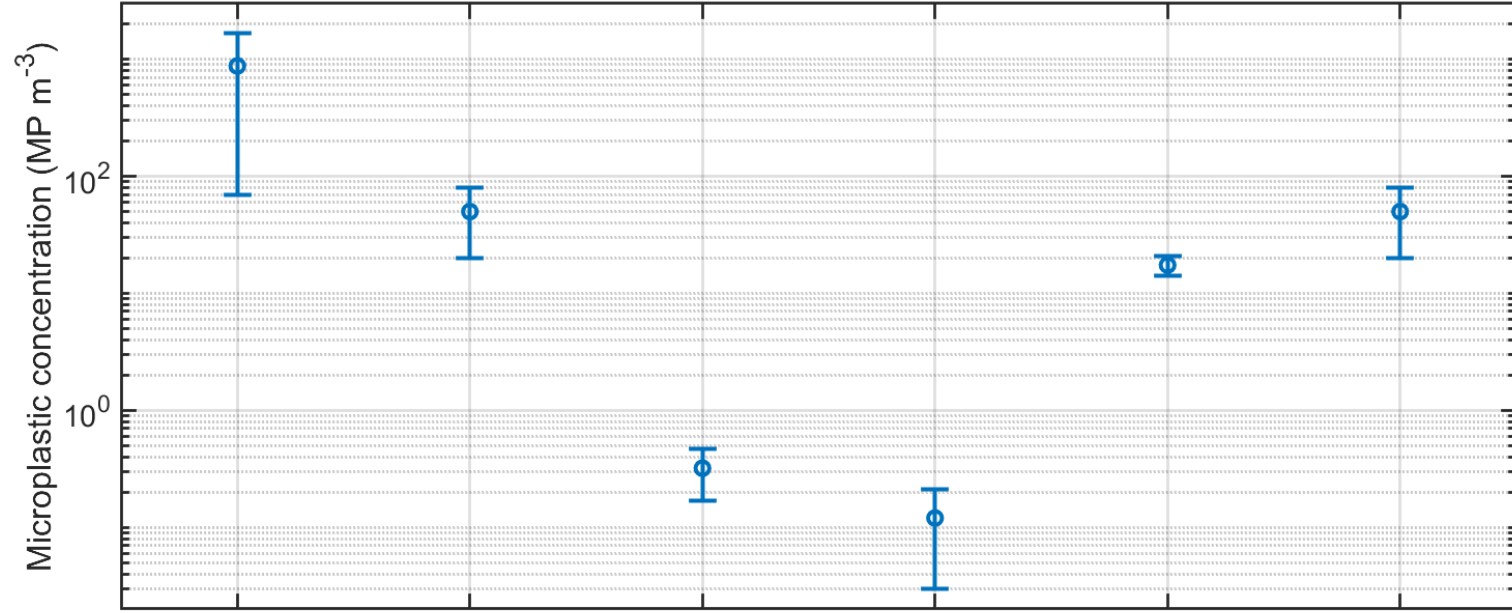


Equipment

- Dekati Elpi+
- Li-Cor 7500, open path
- Sonic anemometer (Gill WindMaster Pro)
- Deposition Box
- 32 μm mesh stainless steel laboratory sieve
- Aethalometer (EA33 Magee)
- Nephelometer (TSI)
- AMS Aerodyne
- Figaero-CIMS
- Custom made DMPS system (University of Helsinki)

Comparison with others, water

Waterborne microplastics in the Indian Ocean region



Maldives (Hanimaadhoo, MCOH)

Maldives (Indian Ocean) - Saliu et al. 2022

Maldives (Faafu Atoll) - Saliu et al. 2018

Maldives (Faafu Atoll) - Saliu et al. 2019

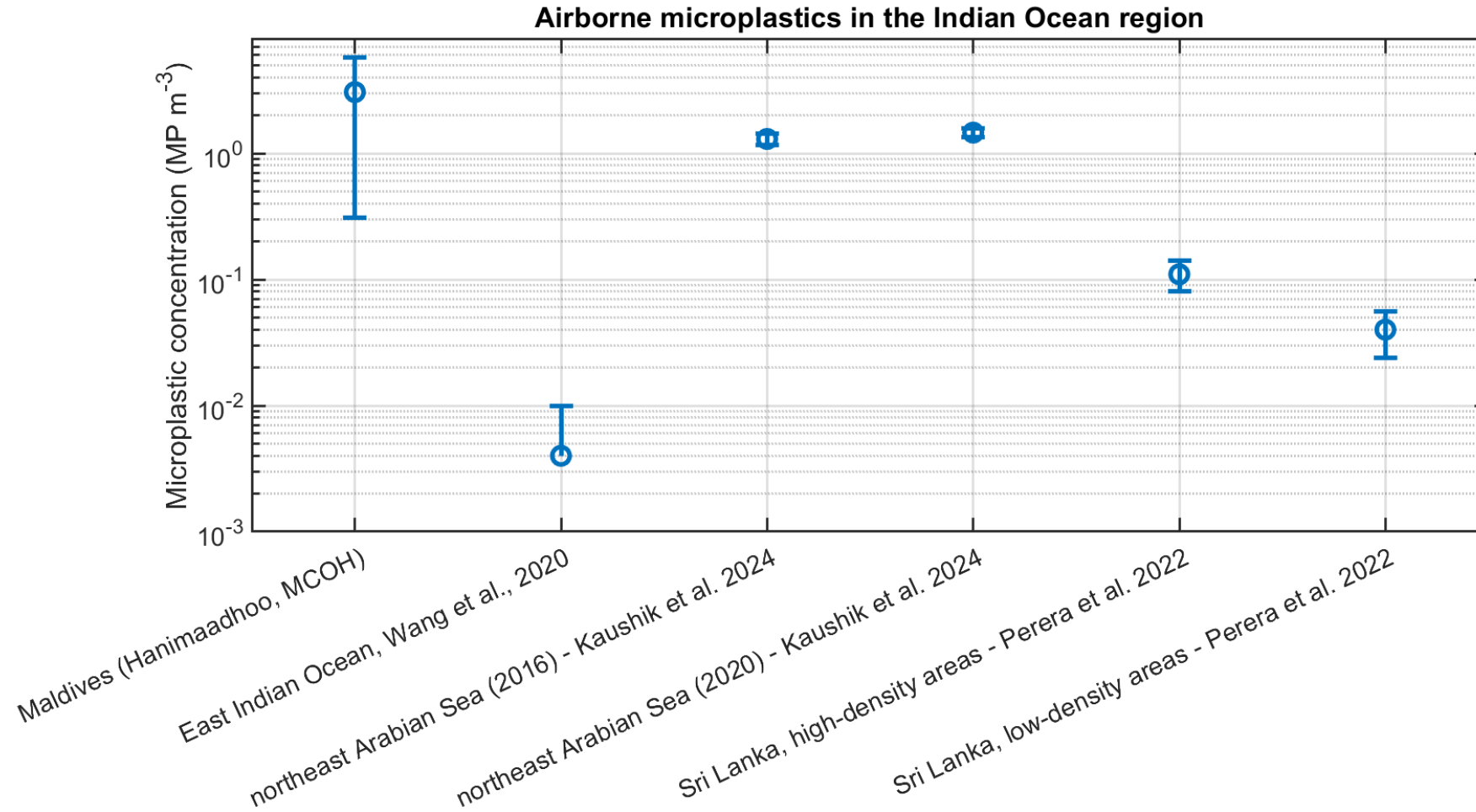
Sri Lanka coast - Athapaththu et al. 2020

Tropical Indian Ocean - Hildebrandt et al. 2022

Overall proportion between fibers and fragments was: 52% to 48%.

In seawater, MP concentrations ranged from 120 to 2690 MP m⁻³, with a mean of 880 ± 810 MP m⁻³.

Comparison with others, air

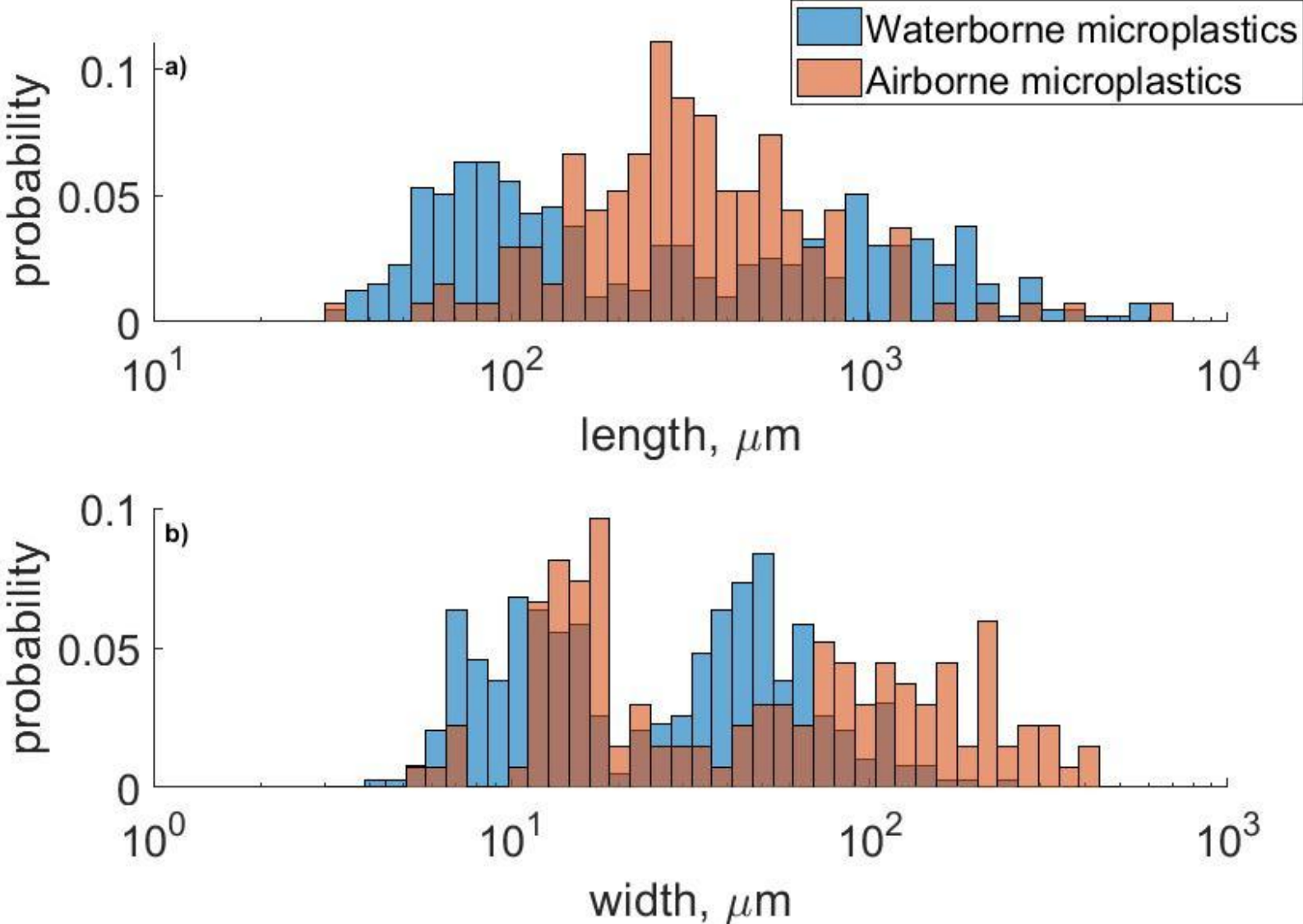


Overall AMP accounted for 9% of TSMP. Among the identified AMP, fibres were the dominant microplastic (61.8%), whereas fragments and films accounted for 38.2%.

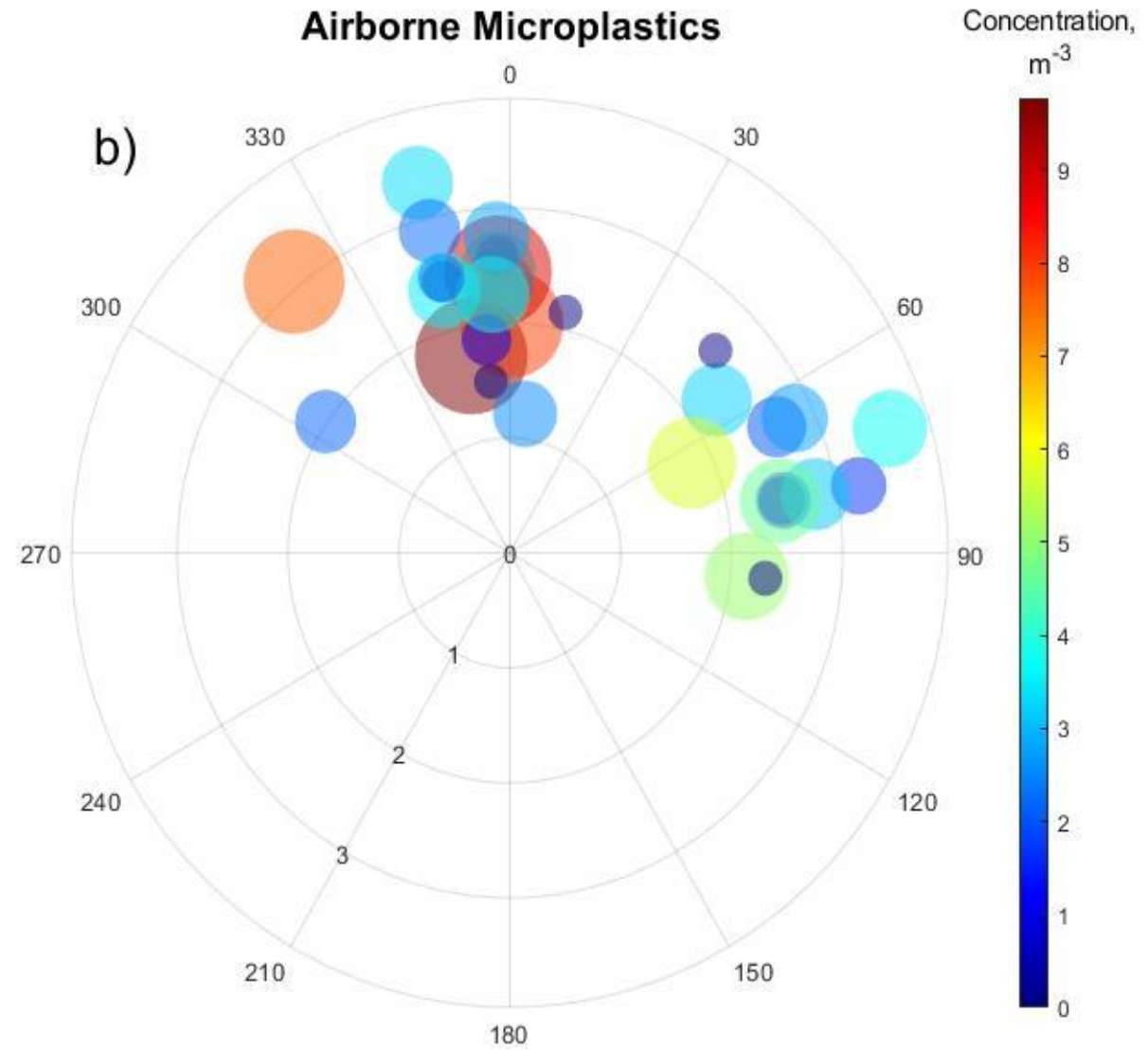
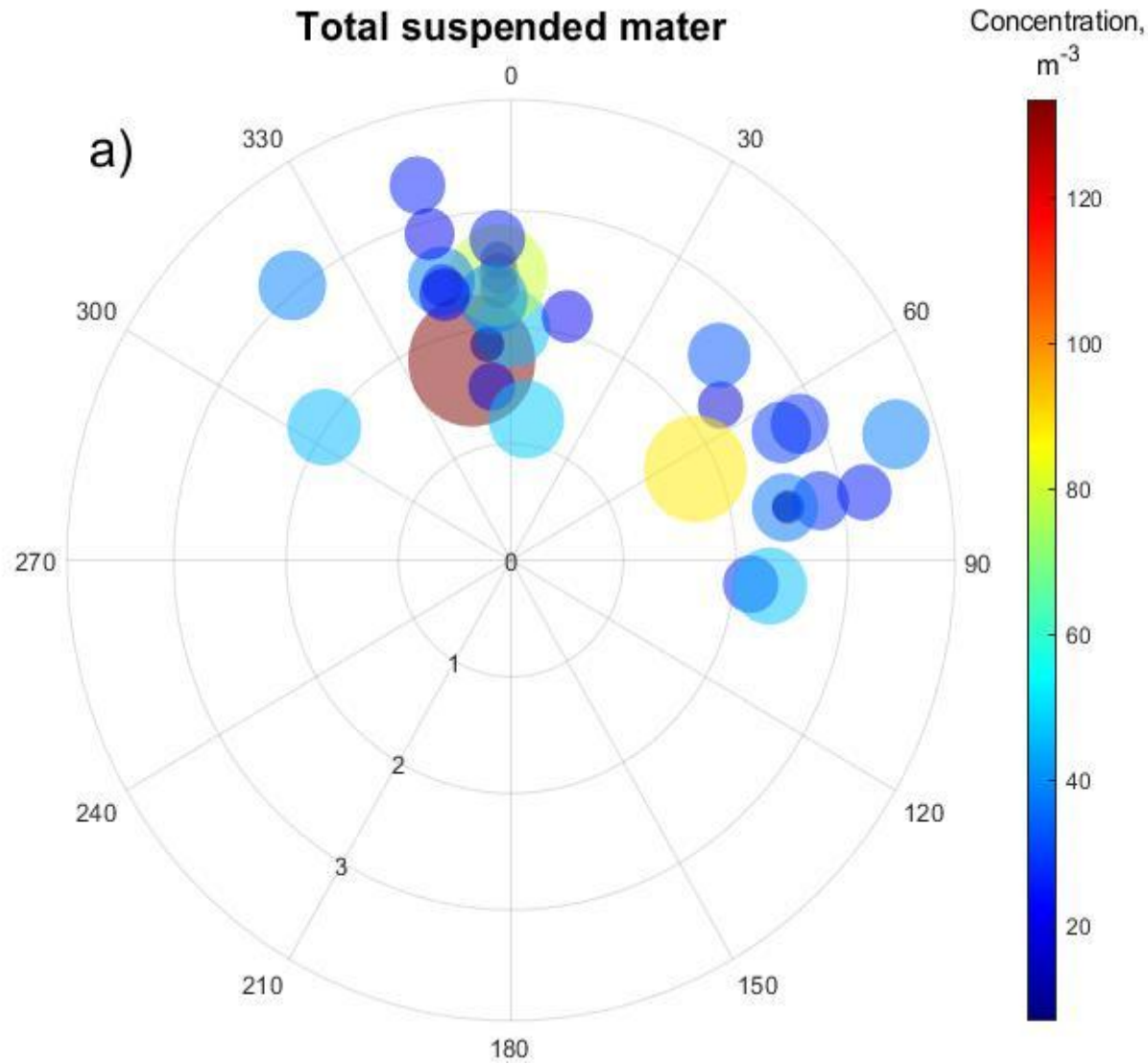
The observed AMP concentrations ranged from 0 to 10.28 m⁻³,

with a mean concentration of 3.06 ± 2.75 m⁻³

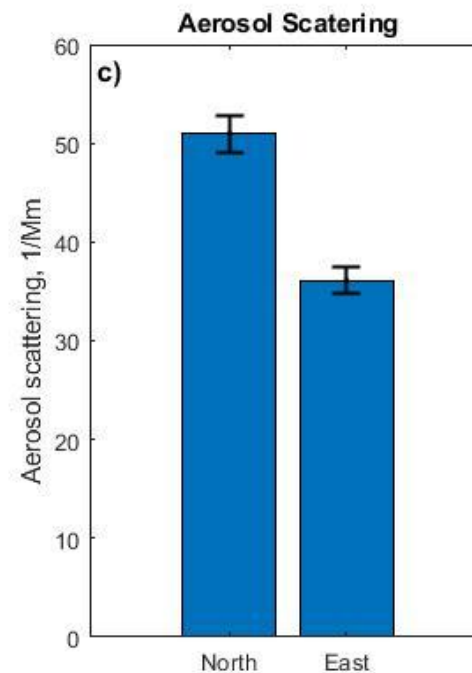
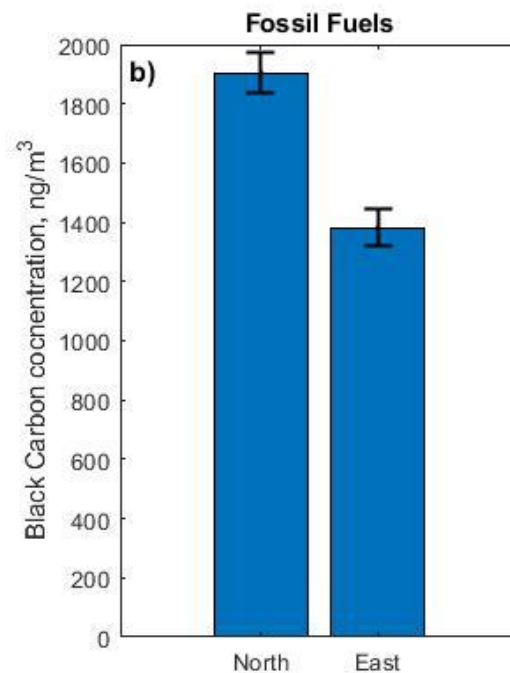
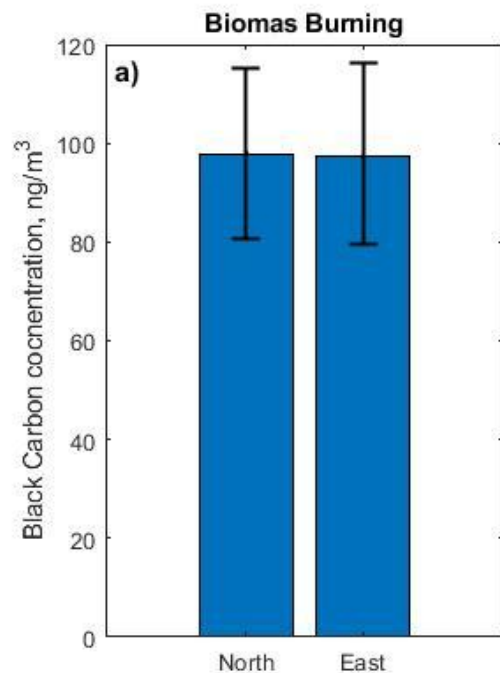
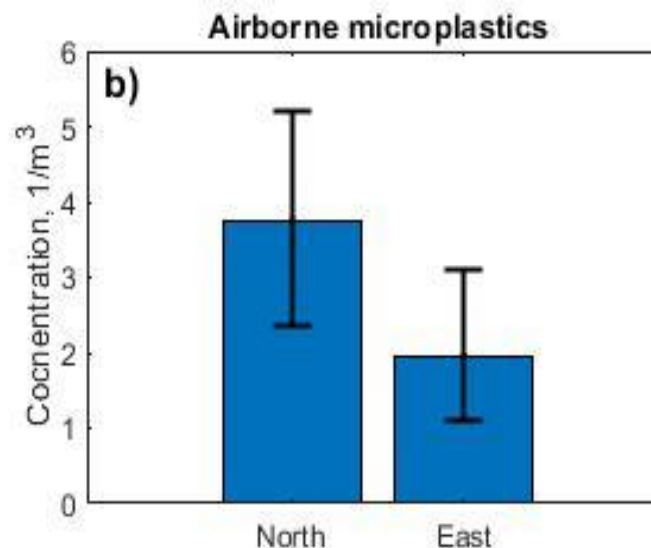
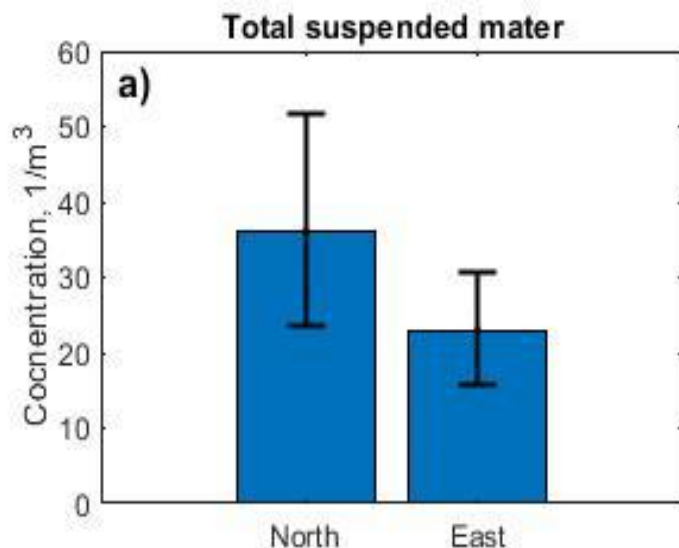
Water vs. air



Prevalent wind and advection patterns



Deposited matter vs. Black Carbon and scattering



Postprocessing done thanks to PolandAOD network and prof. K. Markowicz

BC data filtered for multiple-scattering error:
Müller et al., (2014);
Ferrero et al., (2024)

Source appointment:
Ferrero et al. (2021);
Bernardoni et al. (2021)

Summary

- First microplastic water – air – BC intercomparison in the Indian Ocean region
- More MP in both environments in comparison with other studies
- No PC in the atmosphere (opposite to the Baltic Sea case)
- Significant difference between water and air -> no emission from the sea (low wind speeds=no sea spray emission)
- More deposition than emission
- AMPs respond similar as Fossil Fuels BC and aerosol scattering (in opposite to Biomass Burning)

Challenges

To measure simple AMP gradient (two on-line aspirators) in the Baltic Sea

Baltic and Atlantic comparison – preliminary results

Relaxed Eddy Accumulation for AMP

AMP vs. sodium ionic concentration = enrichment factor

Opus-25: Microplastics in the Baltic Sea and North Atlantic Ocean:
identification and studies of sea-air transport. 2023/49/B/ST10/00513



NATIONAL SCIENCE CENTRE
POLAND

A photograph showing two individuals on a ship's mast structure. They are wearing winter clothing, including jackets and gloves, and are waving their hands. The structure is made of metal railings and has various cables and equipment attached. The background is a clear sky.

Thank you!

pmarkusz@iopan.pl