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Fate and dynamic of Marine Microplastics in the Baltic Sea

CLAIM project: Cleaning marine Litter by developing and Applying Innovative Methods

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Please follow also the talk of **George Triantafyllou** et al.
"Cleaning marine Litter by developing and Applying Innovative Methods (the CLAIM H2020 project)"
EGU OS4.9

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CLAIM: project overview
H2020 Innovation Action

CLAIM

The project covers all aspects of marine micro-and macro plastics

The project covers the Mediterranean Sea and the Baltic Sea, including 15 parners from 14 countries.

INNOVATIVE FORECASTING & MODELLING TOOLS

Collect data, map major sources, develop and apply predictive transport models for forecasting of marine plastic, identify main pathways and heavily impacted areas, develop a validation system (FerryBox)

INNOVATIVE TECHNOLOGY DEVELOPMENT FOR PREVENTION AND MANAGEMENT OF MARINE PLASTIC LITTER

VALIDATION AND DEMONSTRATION

FOSTERING AN ECOSYSTEM APPROACH

ECONOMIC FEASIBILITY, SOCIAL ACCEPTANCE

DISSEMINATION AND OUTREACH

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Micro Plastics:
Where and how much of them is there?

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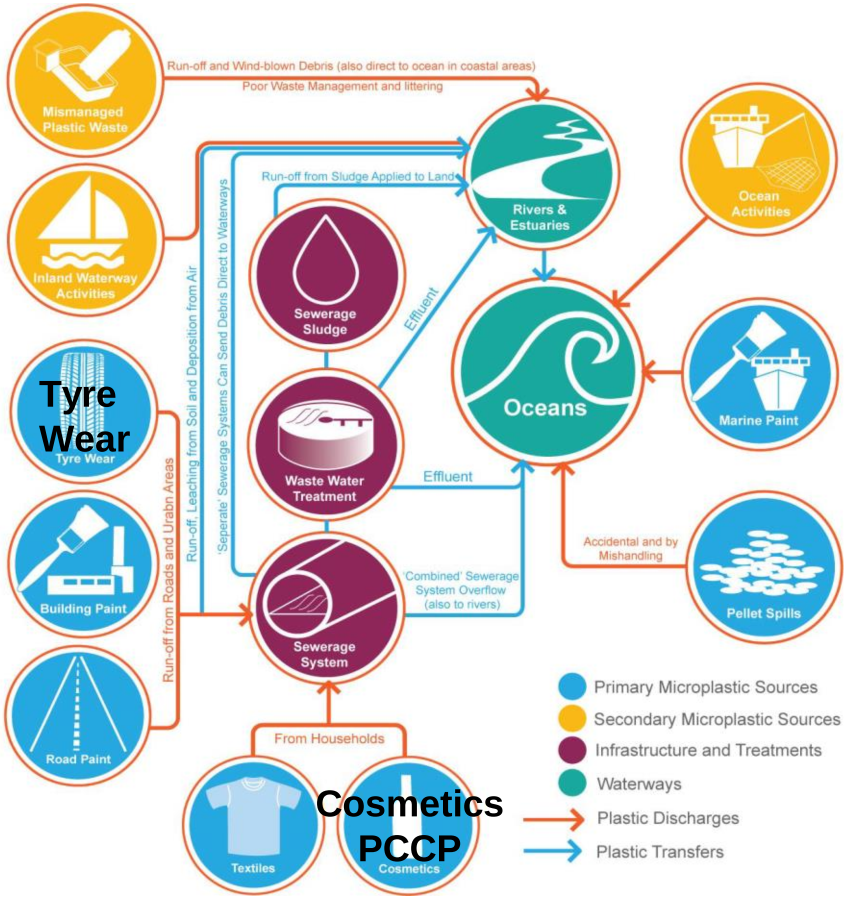
Outlook:

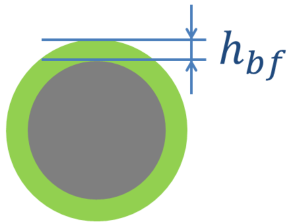
1. ***Overview***
2. ***Sources of micro plastics in the Baltic Sea:*** *Source mapping (nm,…,µm,…,<5mm)*
3. ***Dynamic and drift pattern*** *of microplastics (small/medium/large 5µm/42µm/300µm)*
4. ***Effect of a 30% reduction*** *of river and coastal sources*
5. ***Biofouling****, removal of floating micro plastics ($\rho_{plastic} < \rho_{sea\ water}$)*
6. ***Wave induced drift*** *of micro plastics at sea.*



(Source: Sherrington et al. 2016)

Plastics in the marine environment: Macro, micro- and nano-plastics

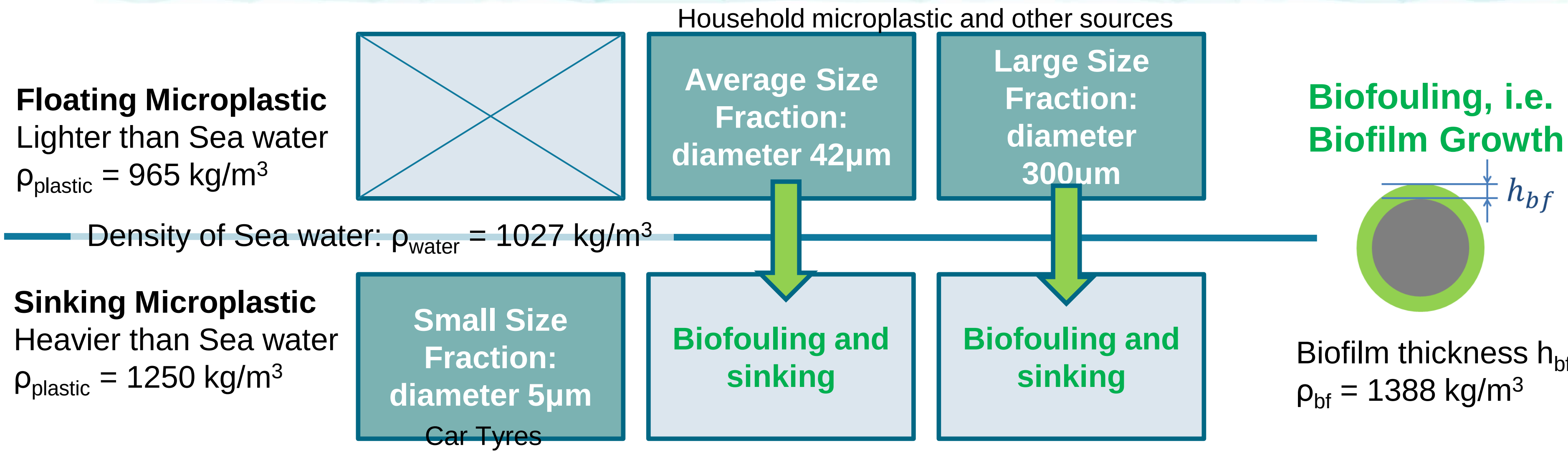
Macro plastic (>5mm), Micro plastic (0.001mm,…,5mm), and Nano plastic (1nm,…,0.001mm)



- ❑ modelled as **spheres** with a certain mass and density
- ❑ Transported by **the currents and wave induced drift**
- ❑ **Biofilm growth** in the marine environment (Shell with thickness h_{bf})
- ❑ **Sedimentation/resuspension**

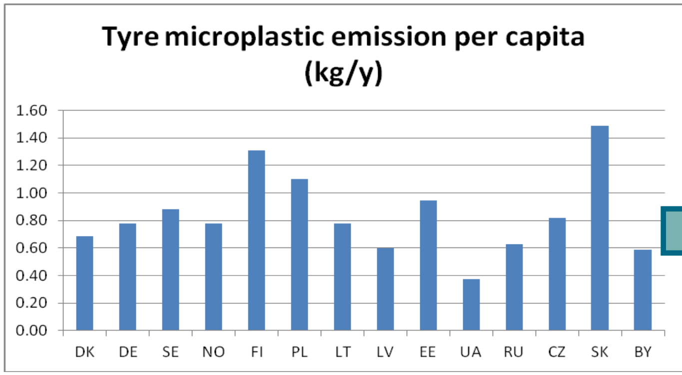
- ➢ Degradation of larger plastic objects (macro plastic) to smaller fragments is not included
- ➢ Currently, only "heavy" micro plastics from car tyres are included in the small size category (5µm). Initially floating micro plastics would spread further over the Baltic Sea basin, due to long residual times, because of low sinking velocities after biofouling.

A more comprehensive overview: Modelling Microplastics in the Baltic Sea

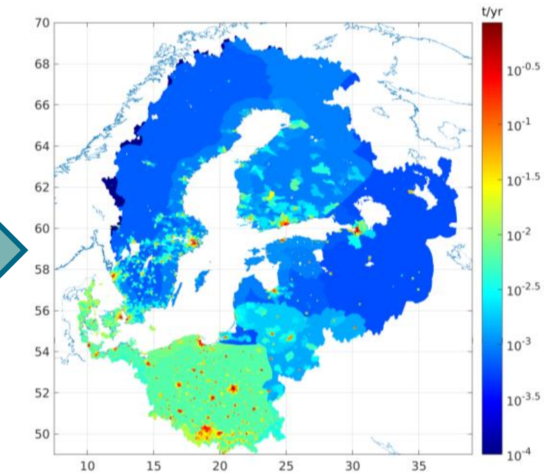


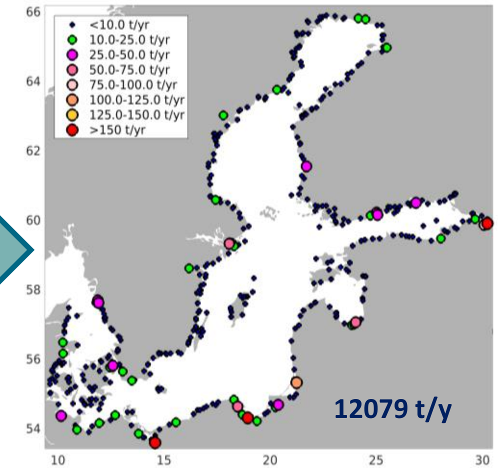
- **Microplastics:** are given as particle concentrations (eulerian tracer). Coastal and river sources are provided
- **Dynamic:** Passive tracer advection of microplastic particles with the mean flow. Includes the effects of wind, current and wave induced drift.
- **Sinking/Raising:** Particles that are heavier than Seawater, sink to the sea bed (small size 5µm). Particles that are lighter than sea water (42µm and 300 µm) raise to the surface until biofouling increases their density sufficiently enough.
- **Sedimentation** of micro-plastics (resuspension not included yet)

Microplastic Sources: Example Tyre Wear and Tear



DK=Denmark, DE=Germany, SE=Sweden, NO=Norway, FI=Finland, PL=Poland, LT=Lithuania, LV=Latvia, EE= Estonia, UA=Ukraine, RU=Russia, CZ=Czech Rep., SK=Slovakia, BY Belorussia





(1.) Emissions: Estimate direct emissions from passenger cars and trucks per country

Input data: Statistics on passenger cars and utility vehicles per country.

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(2.) Pathways: Estimate pathways of microplastics from road transpotation to soil, air, seawage water, WWTP[1], rivers and seas.

Input data:

- ❑ Population density distribution, urbanisation level maps.
- ❑ Statistics on sewage system.
- ❑ Statistics on WWTP[1]s per country (categories, cleaning ratio etc)

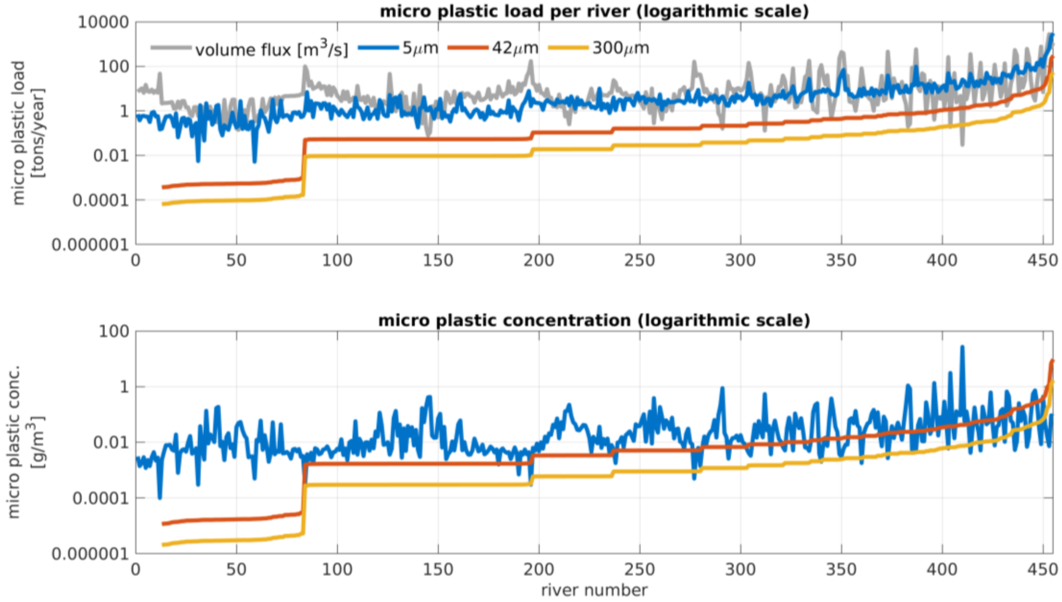
(3.) Sources: Integration over the river catchment.

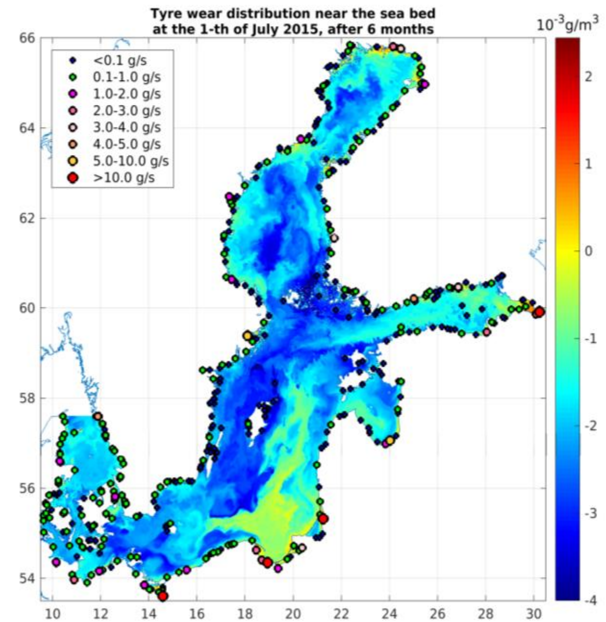
Input data:

- ❑ Catchment distribution
- ❑ River data (discharge, retention ratio etc.)

[1]WWTP stands for Waste Water Treatment Plants

River related inputs into the Baltic Sea





BS estimates range from 887 t/y to 5453 t/y, dependent on the WWTP cleaning factor

- **Mass distribution over size classes** for different plastic types.

1000 t/y
- 15% in size class **300μm** (~measured at sea)
- 85% in size class **42μm** (average size, WWTP efluents[1])

10319 t/y in size class **5μm** (Tyre Wear, fraction that passes WWTP)

- The concentration of micro plastics in the river runoff is constant in time. The micro plastic load scales linearily with the river runoff.

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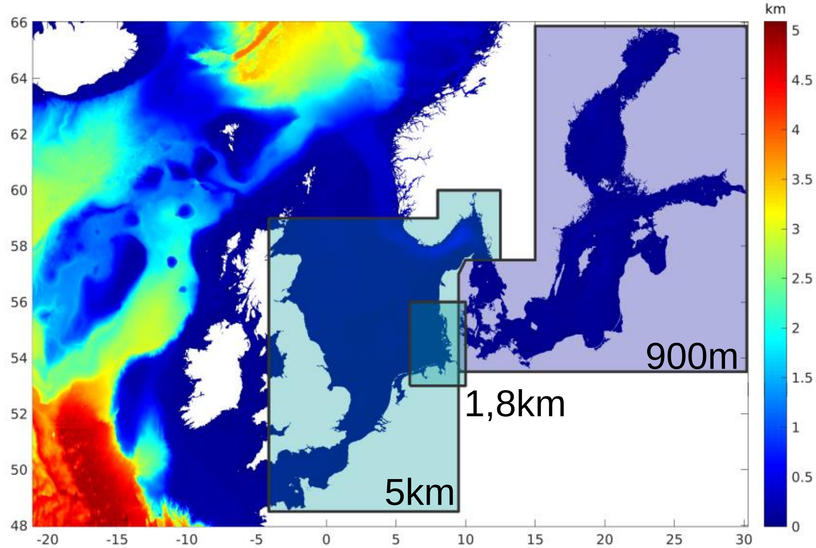
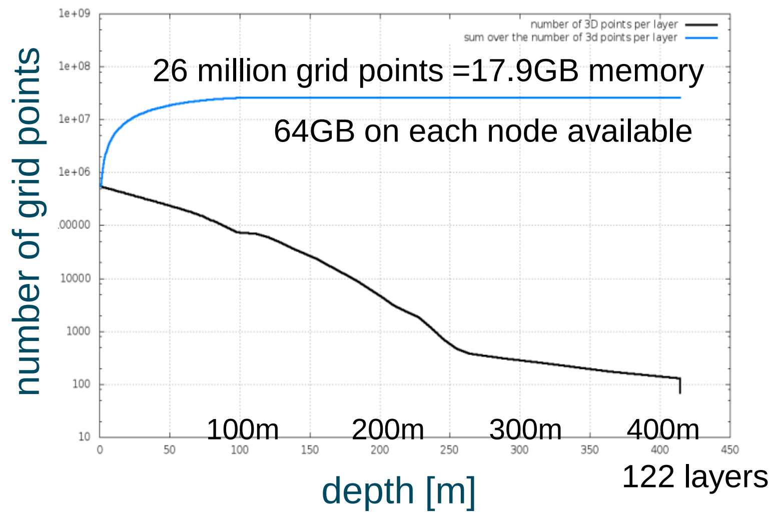
[1]Vollertsen, J., Hansen, A., 2017, Microplastic in Danish wastewater: Sources, occurrences and fate. Environmental Project No. 1906

Modelling micro plastic



HBM setup: Combination of DMI operational storm surge set-up in the North Sea (boundary conditions) and extended high resolution Baltic Sea domain.



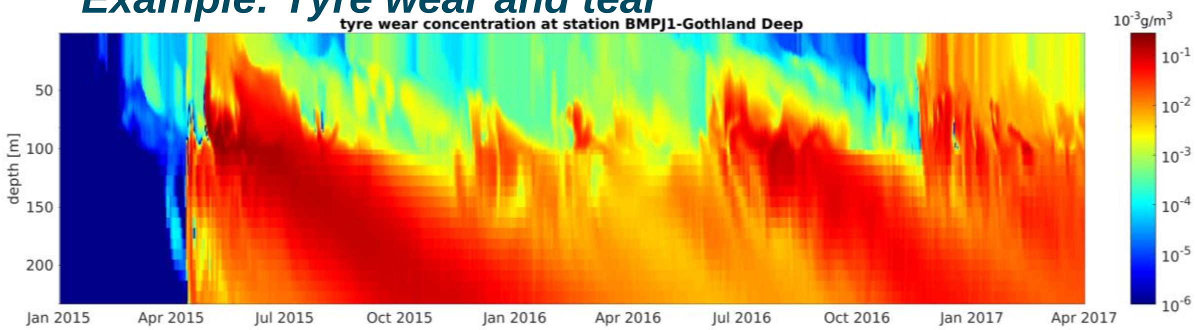
Hydrodynamic: 7-8min for a 24h run with 320 cores.
With eulerian tracer routine: 11.5min on 540 cores

HBM: *3D baroclinic ocean and sea ice model +* ***Eulerian tracer advection model***

- ***Regular spherical-z coordinate*** *,* ***dynamic two-way nesting****, flooding-drying, dynamic stability control*
- *K-omega turbulence (wind-/internal wave effects incl.), Hibler ice thermodynamics + fast ice dynamics*
- *ANSI Fortran90 standard,* ***Hybrid OpenMP-MPI memory parallelisation****,* ***Run2run reproducible*** *, Efficient computing for multi-and many-core architecture, SIMD vectorisation*

Vertical tracer dynamic, i.e. sinking or raising of micro plastics (no biofouling)

Example: Tyre wear and tear



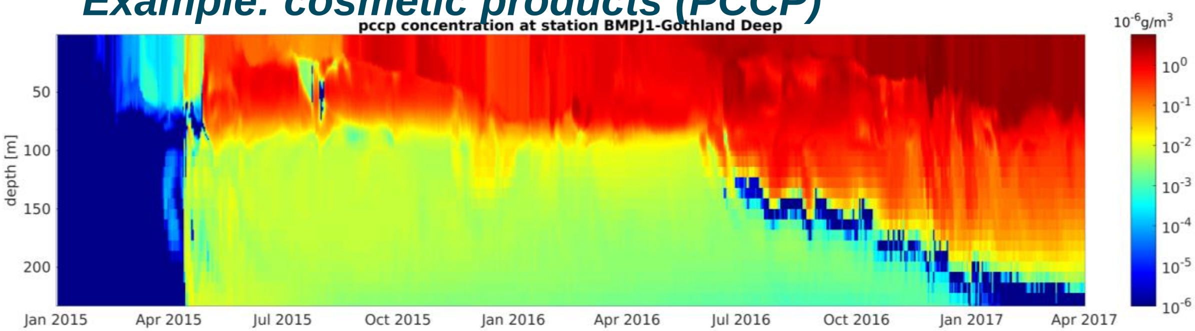
Tyre Wear is heavier than sea water ($\rho_{plastic} > \rho_{water}$) and sinks down to the sea bed.

Stokes formula for sinking velocity

$$w_{sink} = \frac{2}{9}\frac{\rho_{plastic} - \rho_{water}}{\mu} g R^2$$

ρ=density, R=radius, μ=dyn. visc.

Example: cosmetic products (PCCP)



PCCP is lighter than sea water ($\rho_{plastic} > \rho_{water}$) and raises due to his buoyancy to the sea surface.

Without a biofilm shell, the PCCP particles accumulates at the surface. The next slide shows that with a biofilm shell particles eventually sink to the sea bed, where they are embedded into the sediments.

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	Tyre Wear	PCCP	Water
Density (ρ) [kg/m^3]	1250.0	965.0	1027.0
Radius (R) [10^{-6} m]	5.0	3.0	

The effect of biofilm growth (biofouling)

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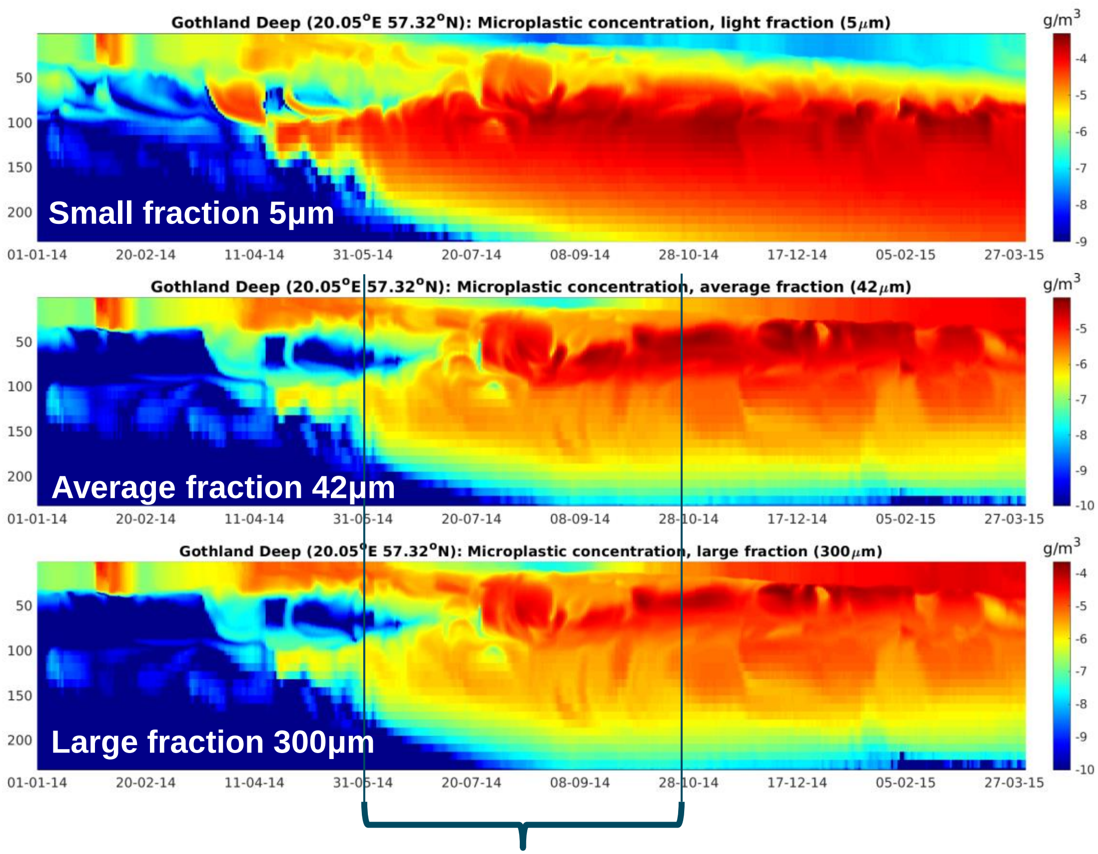

Biofilm growth season

Micro plastics from car tyre are heavier than sea water sink, even without the extra weight of a biofilm shell.

Biofilm growth season: May-October, is determined by the available phytoplankton concentration (chl-a).

It takes roughly 13 days for the average fraction (42µm) and 19 days for the large fraction (300µm) to reach neutral buoyancy.

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Seasonality of Microplastics in the Baltic Sea

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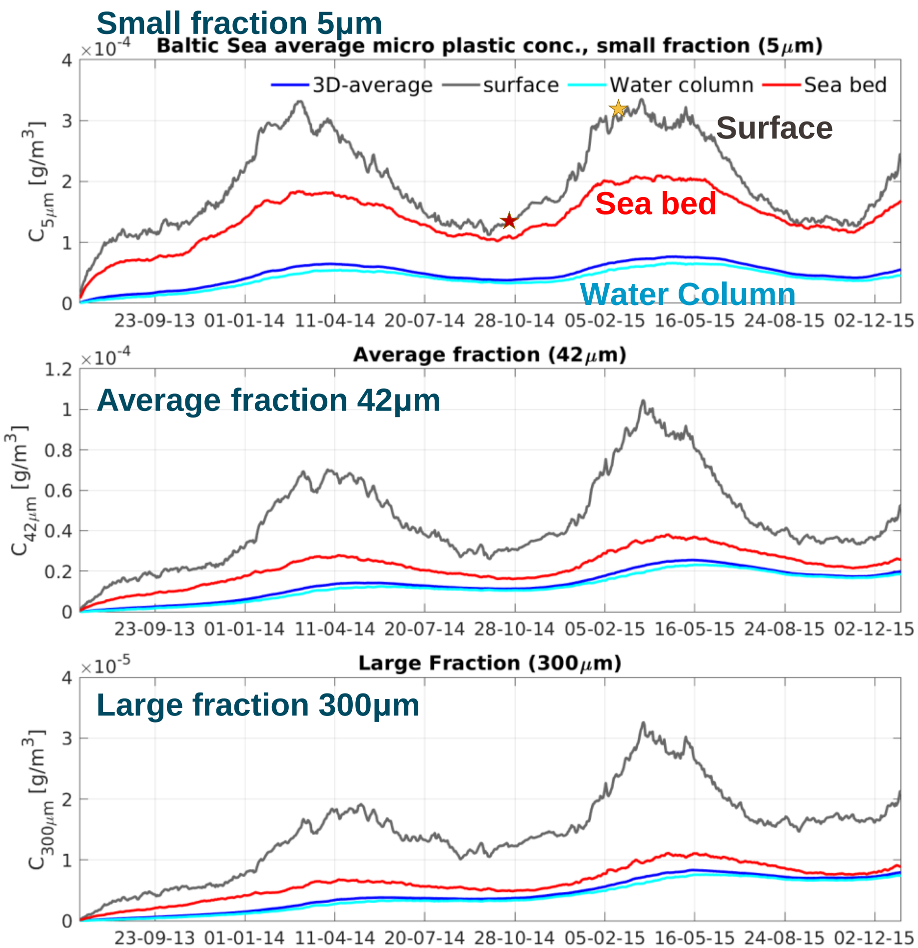

Results from a run with 30% reduced river forcing

Seasonal dynamic of micro plastics

Diffusive transport of microplastics allows them to spread efficiently, from their coastal sources.

Seasonal pattern are established; due to

- annual river runoff cycle
- Biofilm growth (chl-a dependent, roughly from May to October)
- sinking/sedimentation in summer and enhanced mixing in winter

Highest concentration occure near the *surface (horizontal transport, buoyancy dependent upwards raising)* or near the *sea bed (growth of a heavier biofilm shell and sinking).* Low concentrations occur in the water column. This is in good agreement with observations.

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Experiments with 30% reduction of river and other coastal sources

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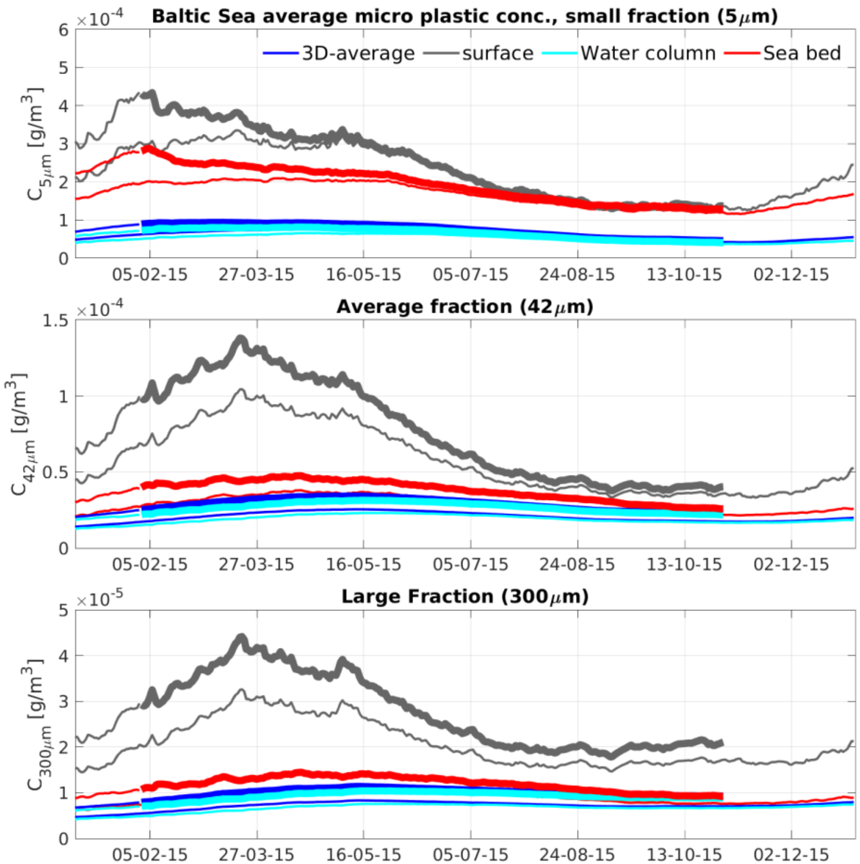

Small-but-heavy micro plastics (5µm) from car tyre show fast improvement, because thy are heavier than sea water and sink eventually to the sea bed. The sinking velocity does not depend as much on the season.

Average fraction micro plastics (42µm) adjust slowly, to the 30% reduced inputs. Their sinking velocity depends on the biofouling rate, and is therewith seasonally dependent.

Large fraction micro plastics (42µm) adjust even slower, to the 30% reduced inputs. Their Biofilm growth rate is lower than the average fraction. It takes more time to overcome their buoyancy.

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Small fraction (5µm): Transport pattern in the Baltic Sea (monthly mean maps)

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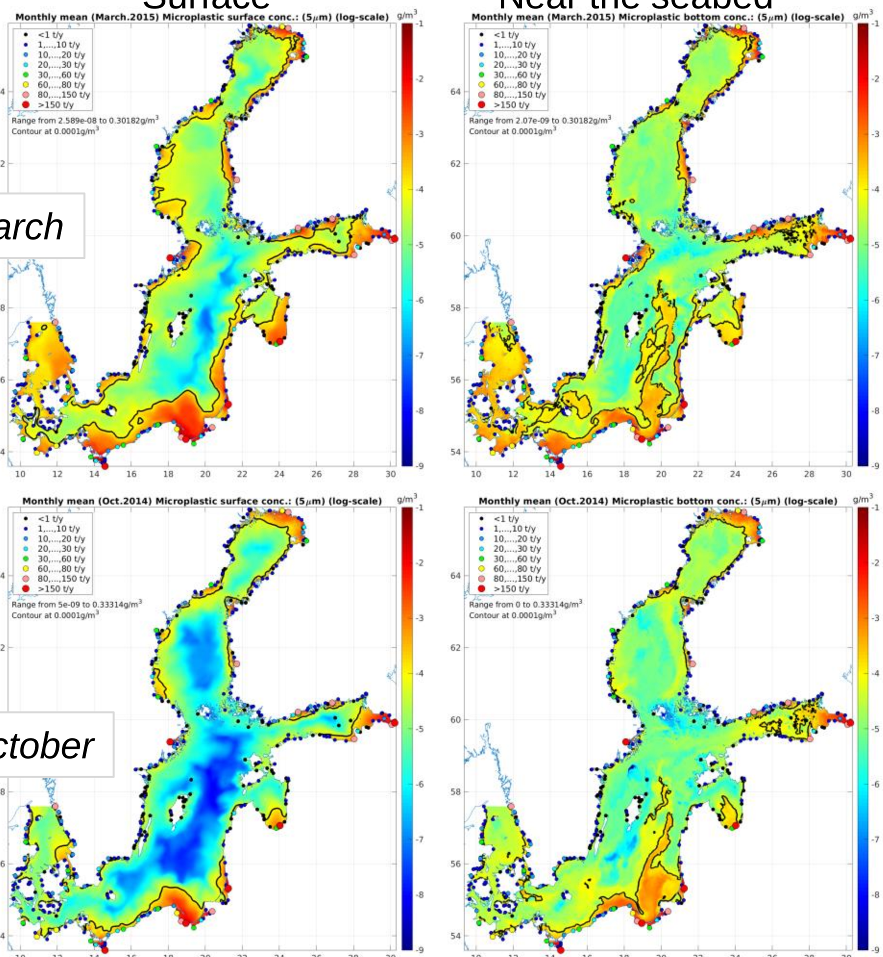
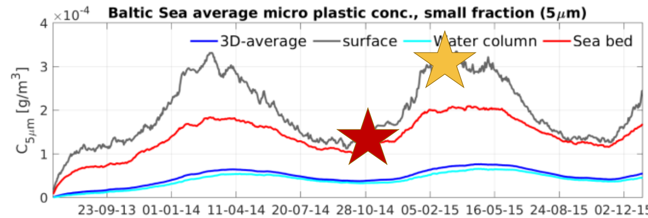
Surface | Near the seabed

March

October



Contours mark areas with concentrations larger than 10^{-3} g/m³



March:

Increased river runoff and reduced biofilm growth rates (low concentrations of chl-a) leads to a maximum of micro plastic concentration in early Spring.

Tyre wear is heavier than sea water and sinks to the bottom of the ocean, where it forms layers of higher concentration in the Gothland deep and the southern Baltic Propper.

October (over Summer):

Sedimentation is implemented as a slow removal process.

Mixing and transport is further removing the tyre wear concentration near the sea bed.

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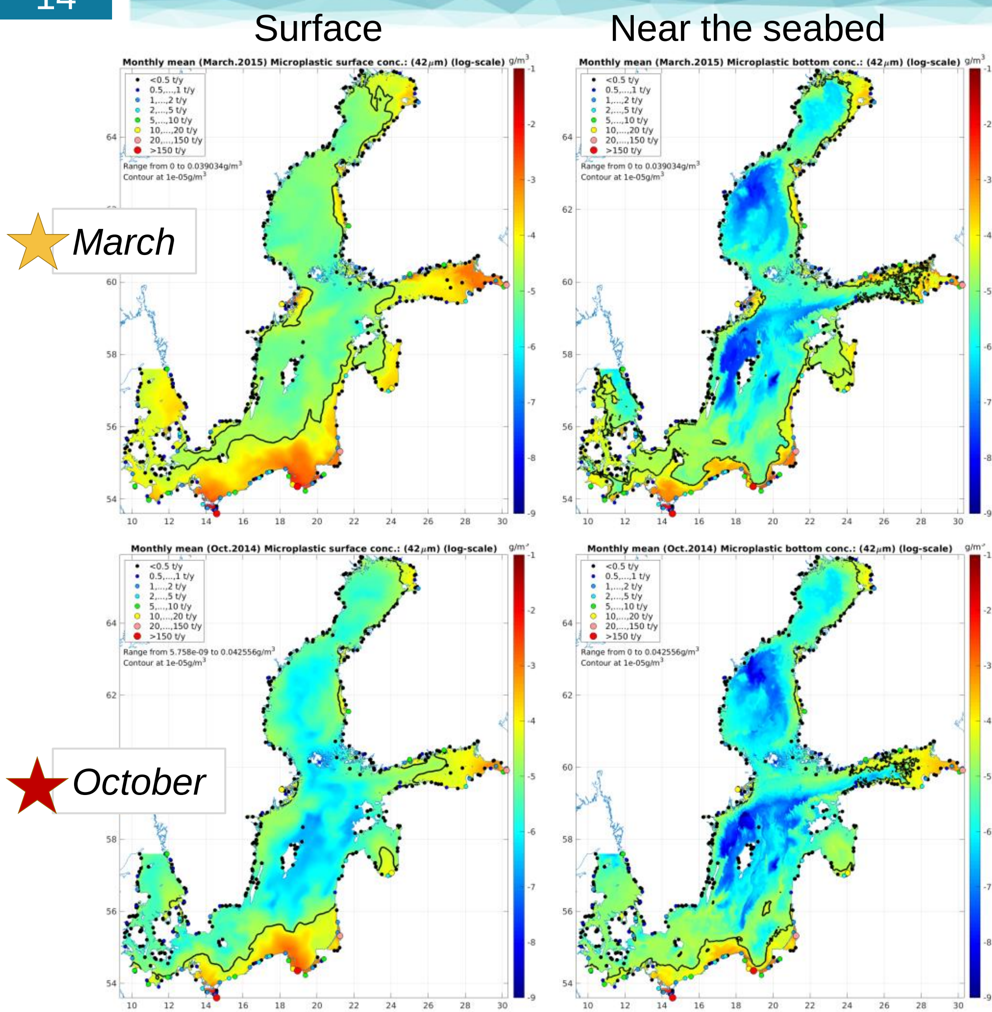
Average fraction (42µm): Transport pattern in the Baltic Sea (monthly mean maps)



March:
Increased river runoff and reduced biofilm growth rates (low concentrations of chl-a) leads to a maximum of micro plastic concentration in early Spring.

October (over Summer):
Biofouling, i.e. the growth of a biofilm shell increases the density of particles near the surface until sinking sets in. Sedimentation is implemented as a slow removal process.

Pathways:

1. *Sediment Seeding:* Horizontal transport near the surface, density increase due to biofouling and finally sinking and sedimentation.
2. *Deeper Sea transport:* Density increase due to biofouling and basin-to-basin transport with the meand flow.

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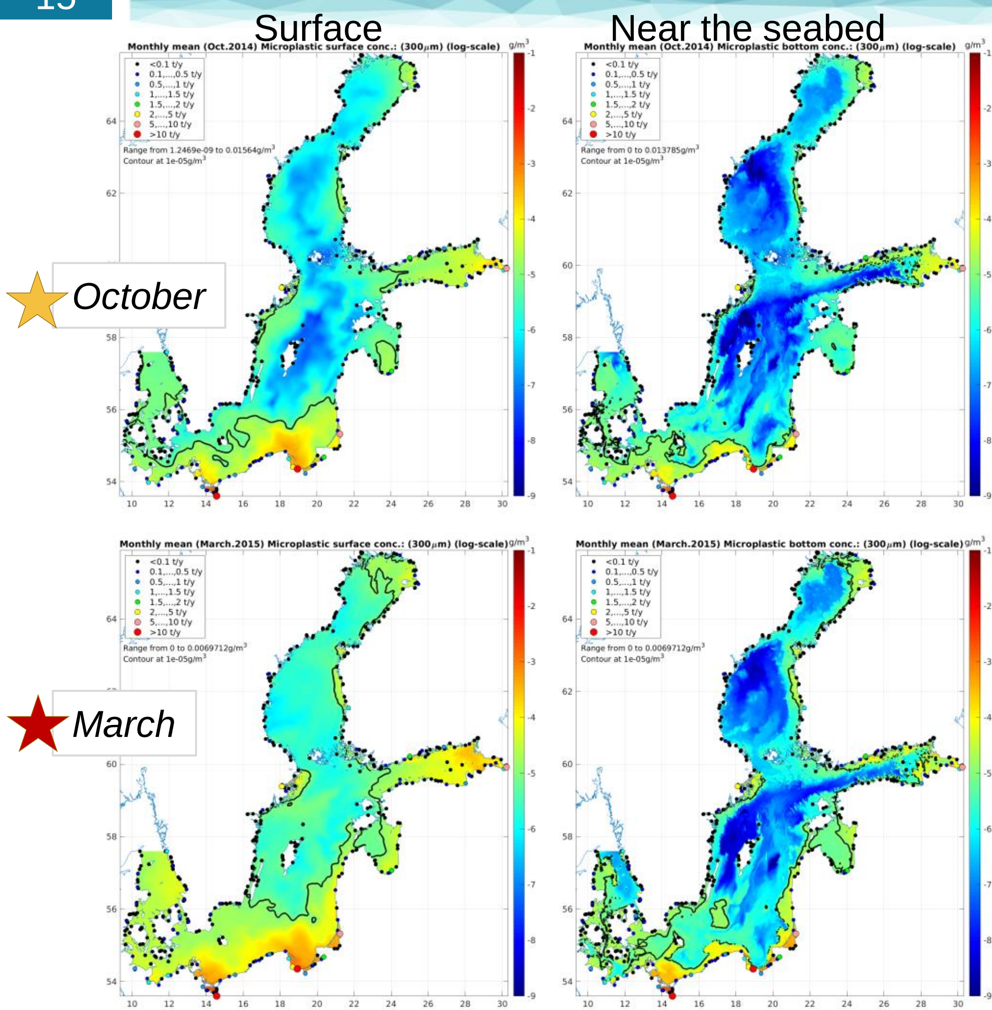
Large fraction (300µm): Transport pattern in the Baltic Sea (monthly mean maps)



March→ October

Seasonal dynamic is dominated by seasonal changes in river runoffs, chl-a dependent biofilm growth and sinking and sedimentation.

Biofilm growth dependent transport:

The buoyancy of the large fraction (300µm) is more difficult to overcome than the buoyancy of the average fraction (42µm). Therefore, large size microplastics spread further horizontally, before they sink (sediment seeding).

Pathways:

1. *Sediment Seeding:* Horizontal transport near the surface, density increase due to biofouling and finally sinking and sedimentation.
2. *Deeper Sea transport:* Density increase due to biofouling and basin-to-basin transport with the meand flow.

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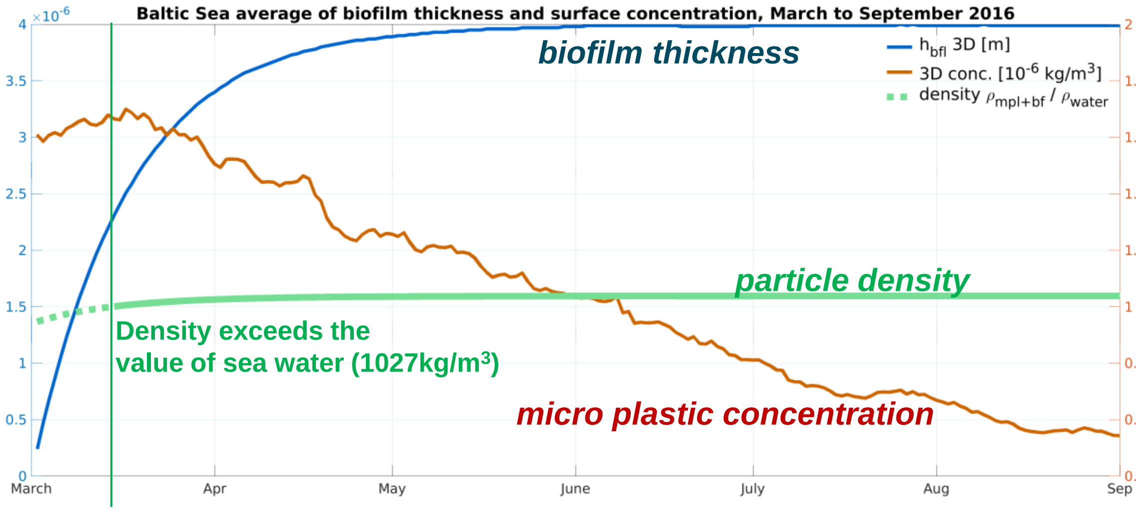
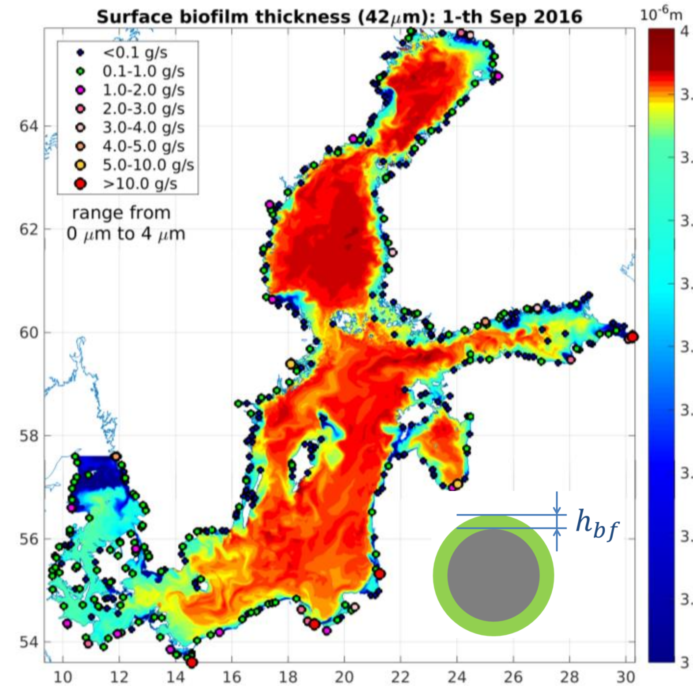
Processes (1.): Biofouling, a simplified approach





Biofouling: Simplified model for biofilm growth

- Saturated growth function for biofilm thickness h_{bf}
- h_{bf} is advected as a "passive" tracer and is transported vertically by sinking/raising
- Seasonality has been implemented as chl-a debpendent growth process
- The simplified model does not take into account:
  → encounter and growth of algae in the sea water
  → North Sea boundary input

Simplified biofilm growth model

$$\frac{dh_{bf}}{dt} = \frac{h_{max}}{T_{sat}}\left(1 - \frac{h_{bf}}{h_{max}}\right)$$

with $h_{max} = 4\mu m$
$T_{sat} = 16.2\ days$

Processes (1.): *Biofouling, a simplified approach*

Effects of Biofouling: (simplified model)

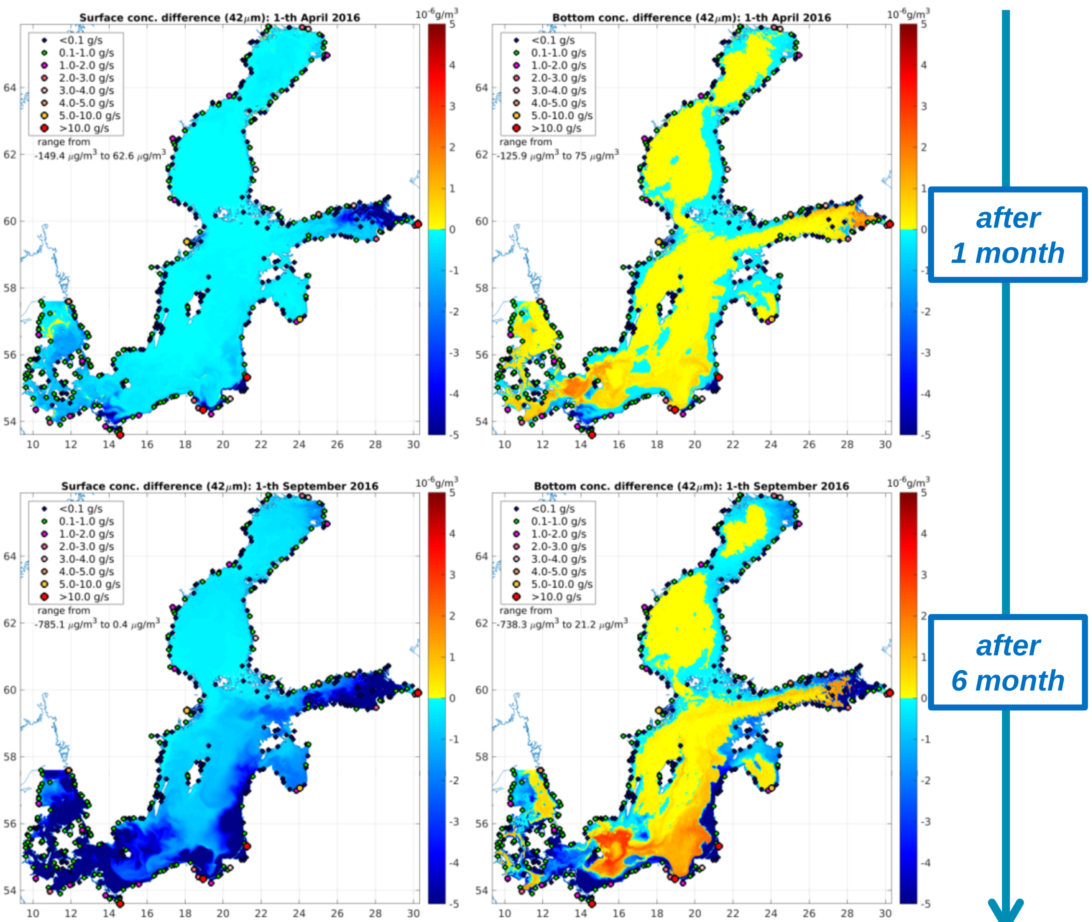
- Enhanced effect of biofouling and sinking in the Southern Baltic Sea and the eastern Gulf of Finland; due to higher micro plastic concentrations.

Chl-a dependent growth fuction:

- growth limiter of 1.1mg/m^3 implemented, to include seasonality
- chl-a dependent growth functions are under development

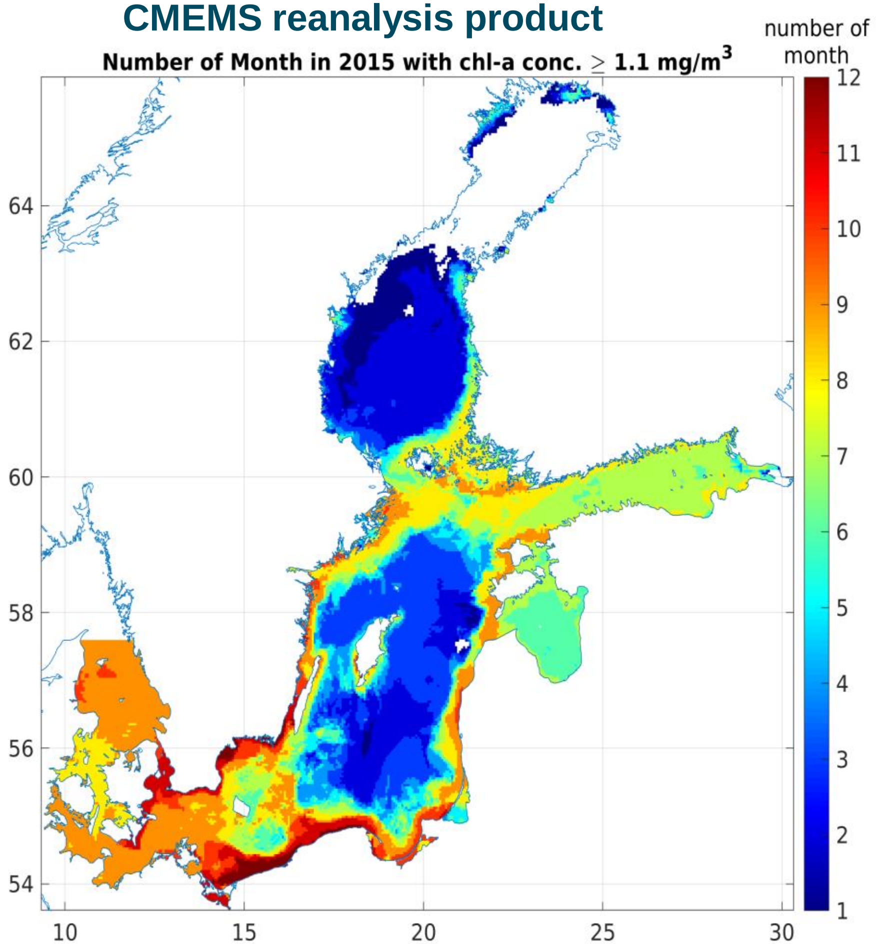
Realistic modelling of biofilm growth:
Model from *Kooi et al 2017*, including

- encounter of algae
- light and temp. dependent growth functions
- grazing and respiration.



Biofouling, first steps towards a chl-a (algae) dependent growth function

Seasonal pattern of chl-a in 2015, CMEMS reanalysis product



Motivation:

- ✓ seasonally varying pattern of biofilm growth
- ➢ improved vertical localization of biofilm growth in the euphotic zone

Implementation

- chl-a concentration dependent growth limiter: 1,1 mg/m^3
- Considers only surface concentrations

Further upgrades, next steps:

- chl-a dependent growth function
- full 3d implementation
- light attenuation dependent growth of biofilm

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Process (2.): Wave induced drift of plastic pollutants.

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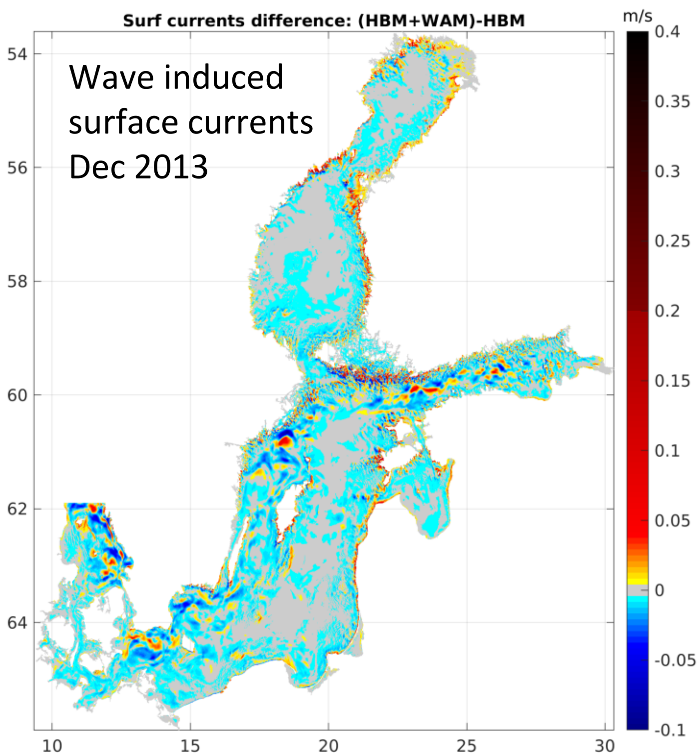

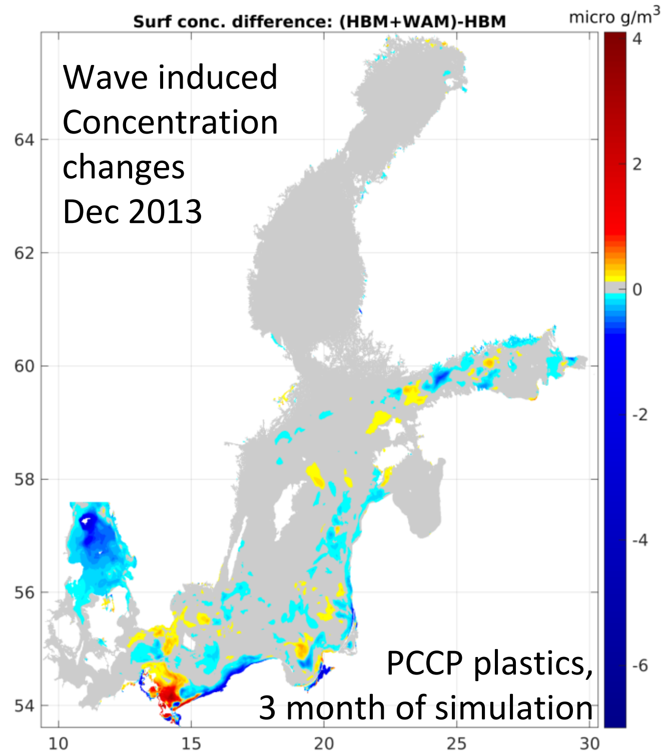

Wave induced transport (monthly mean):

- reduced conc. along the southern and eastern shores
- enhanced release of micro plastics from the Odra delta

Coupled wave and ocean circulation modelling:
Waves have been implemented as a driving force to the surface currents (divergence of the radiationstress).

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Taking home message:

- Successful development of a micro plastic drift- and fate model, including parameterizations for the essential processes:
  biofilm growth, density dependent sinking/raising, wave-and current induced drift, sedimentation.
- *S*easonal dynamic of micro plastics established
- Modelling of drift pattern for the identification of accumulation zones and heavily polluted areas.
- Impact studies of a 30% reduction scenarios show fast improvement for micro plastics from car tyre (within 1 year), which are heavier than sea water and a slower adaptation for other sources, which require biofouling for sinking.
- Micro plastic source mapping introduction: tyre wear, cosmetic products and laundry wash, including comprehensive literature studies and integration.
- Baltic Sea high resolution drift model (926m, horizontally): modelling of small scale eddies with a size of a few kilometers

Next developments, currently unresolved processes

Further Studies
Study the dynamic of small and initial buoyant micro plastics, which have much longer residence time and spread much further across the Baltic Sea.

Open questions, unresolved processes
- Sources: Seasonally varying micro plastic concentrations, retention in rivers
- Resuspension/erosion of sediments and related micro plastic input near the sea bed (wave induced mixing)

Further developments, next steps
- Biofouling model: Chl-a dependent growth function
- Wave induced pollutant drift: 3D implementation, 2-way coupling

Thank you

THANK YOU

QUESTIONS?