CLAIM project: Modelling drift and fate of micro-plastics in the Baltic Sea

CLAIM: Cleaning marine Litter by developing and Applying Innovative Methods

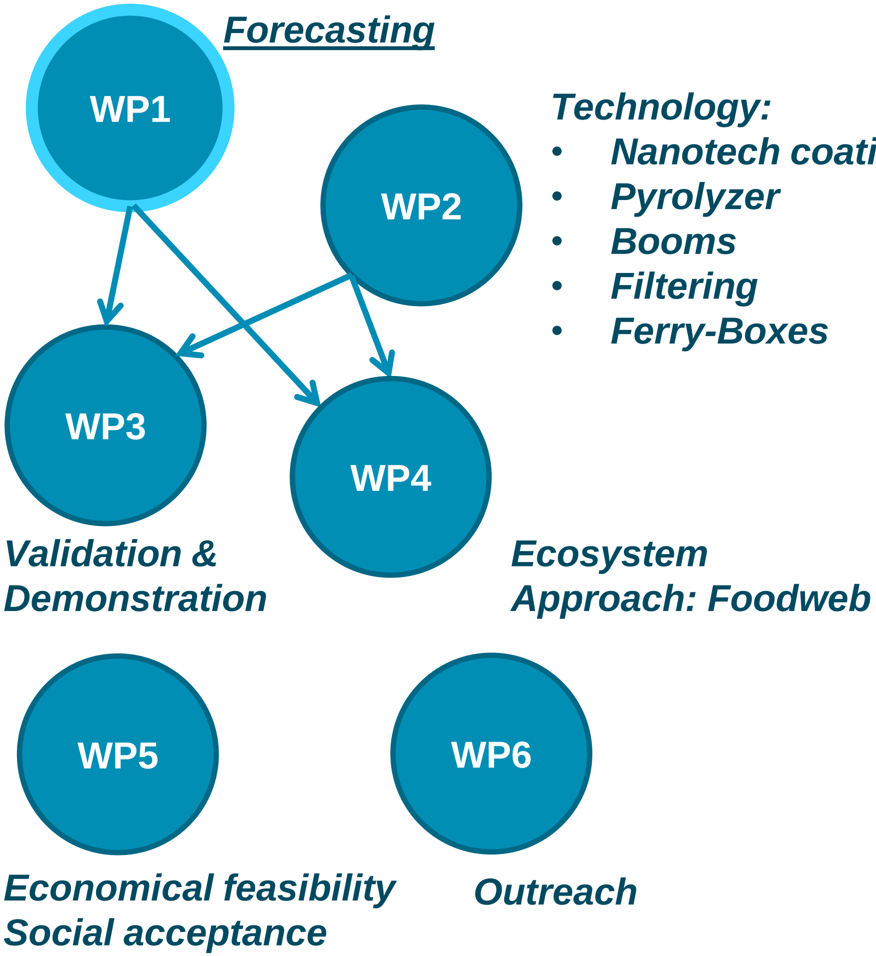
Jens Murawski, Jun She (DMI)

BOOS Annual Meeting

12.06.2019

European Commission
Horizon 2020
European Union funding
for Research & Innovation

CLAIM: project overview
H2020 Innovation Action



Technology:
- ***Nanotech coating***
- ***Pyrolyzer***
- ***Booms***
- ***Filtering***
- ***Ferry-Boxes***

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

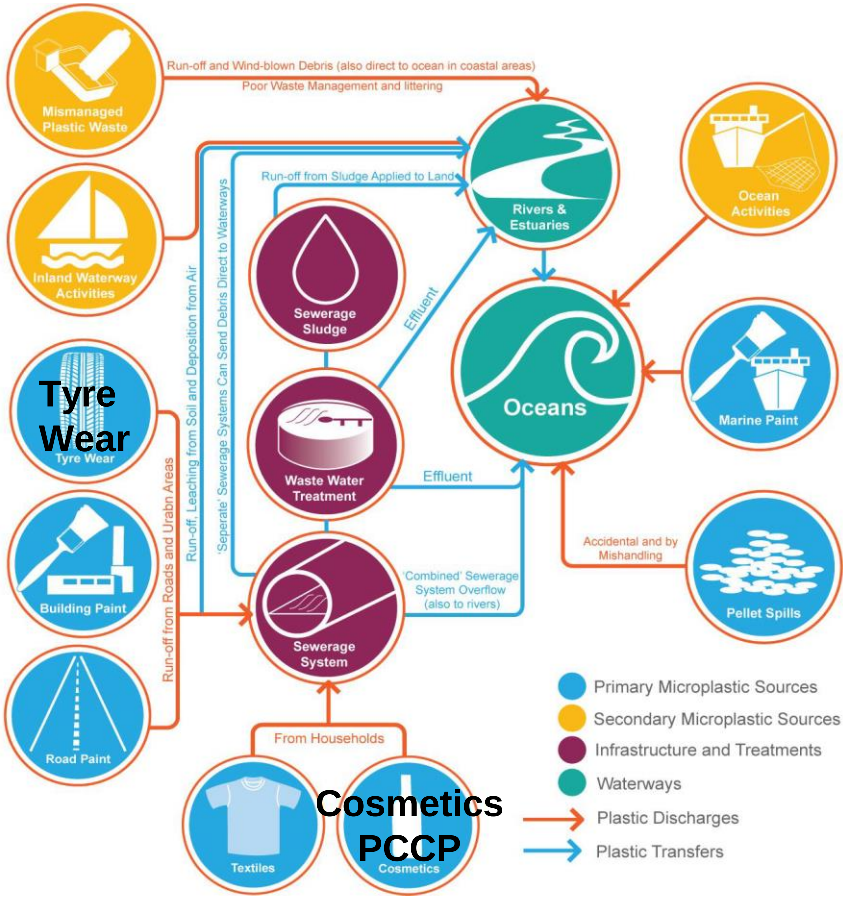
Outlook:

1. ***HBM model set-up and river input of micro plastics,*** *Source mapping (nm,…,µm,…,<5mm)*

2. ***Dynamic and drift pattern*** *of PCCP-cosmetics and Tyre wear micro plastics*

3. ***Biofouling****, removal of floating micro plastics ($\rho_{plastic} < \rho_{sea\ water}$)*

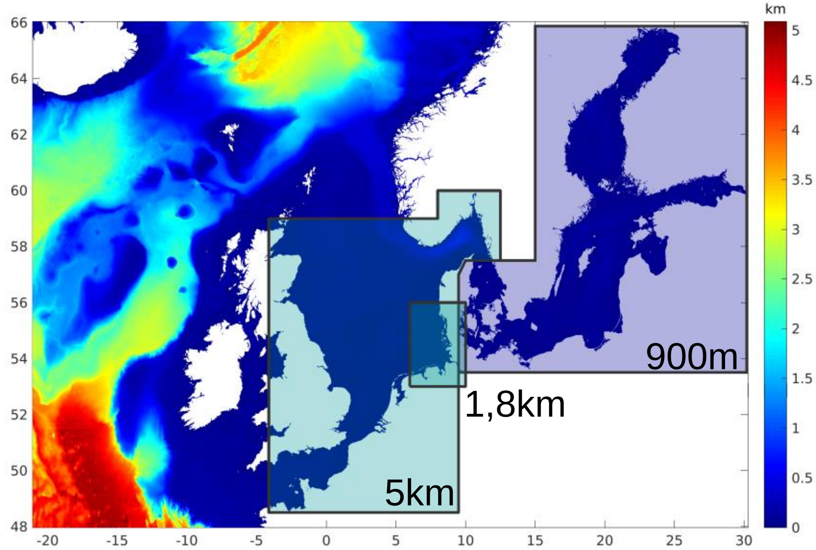
4. ***Outlook:*** *(1.) wave induced drift and (2.) resuspension of micro plastics at sea.*



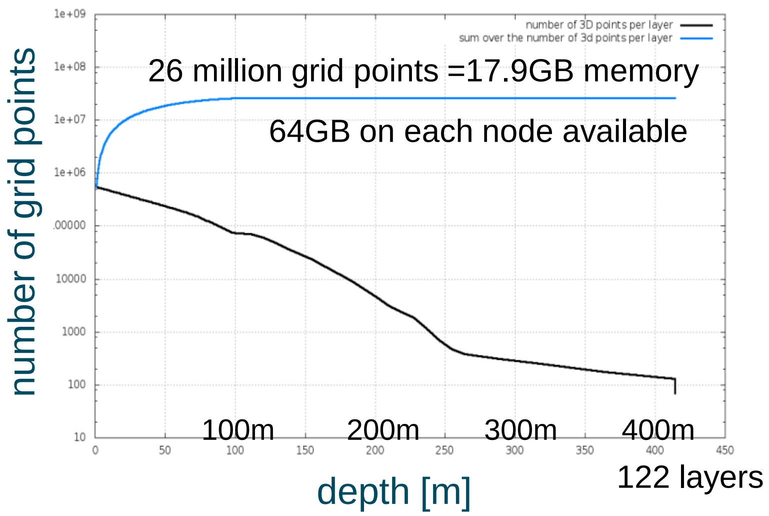
(Source: Sherrington et al. 2016)

European Commission | Horizon 2020 European Union funding for Research & Innovation

HBM model development



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

- *K-omega turbulence (wind-/internal wave effects incl.)*
- *Stability /structure functions: Canuto III with added realisability conditions*
- *Ice thermodynamics + fast ice dynamics*
- *Coupled to Eulerian tracer advection routine, now including the effect of sinking and raising.*
- *Test platform for biofouling established.*

European Commission | Horizon 2020 European Union funding for Research & Innovation

River related inputs into the Baltic Sea, example PCCP

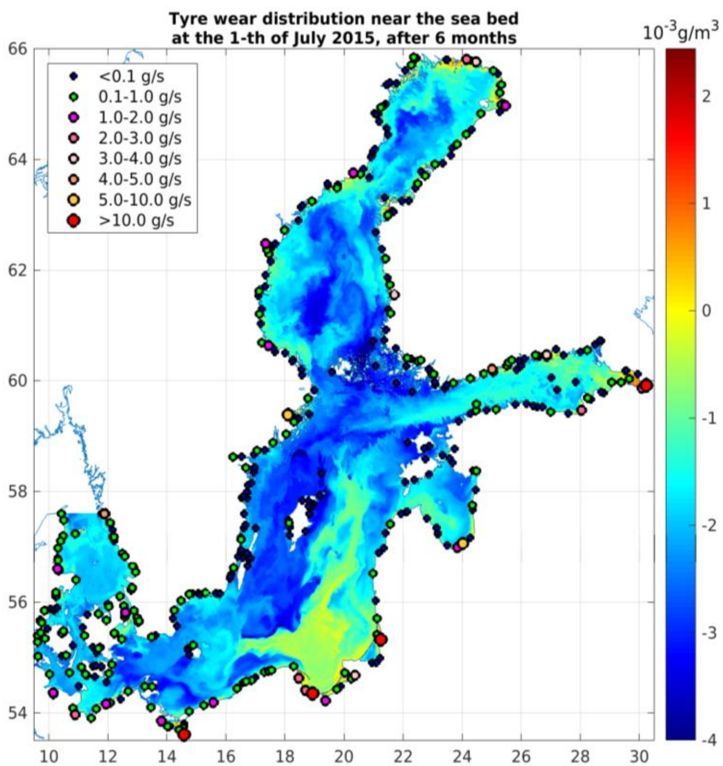


Figure above: Tyre wear related micro plastic concentration [milli g/s] in the Baltic Sea.

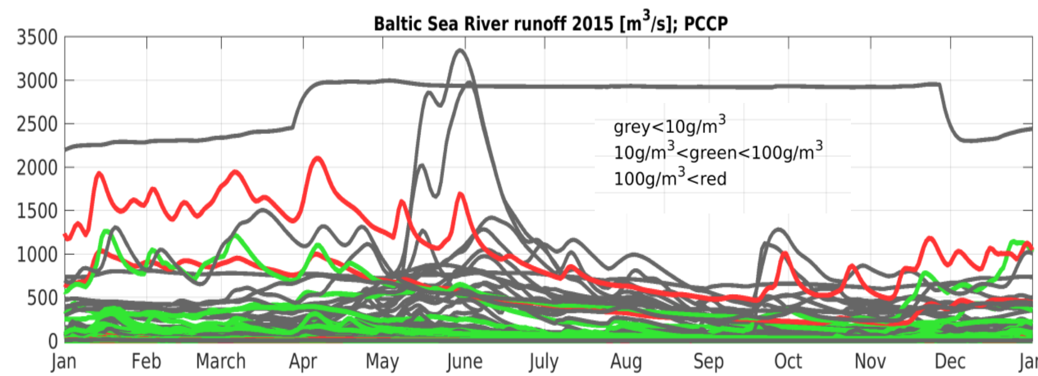


Figure above: Baltic Sea river run-off [m^3/s] with color coded river input of tyre wear related micro plastics [g/s] of the 455 rivers considered in the model setup. The two rivers with the largest micro plastic contribution (red) are the Oder (1-th) and Vistula (2-nd).

Main assumption:

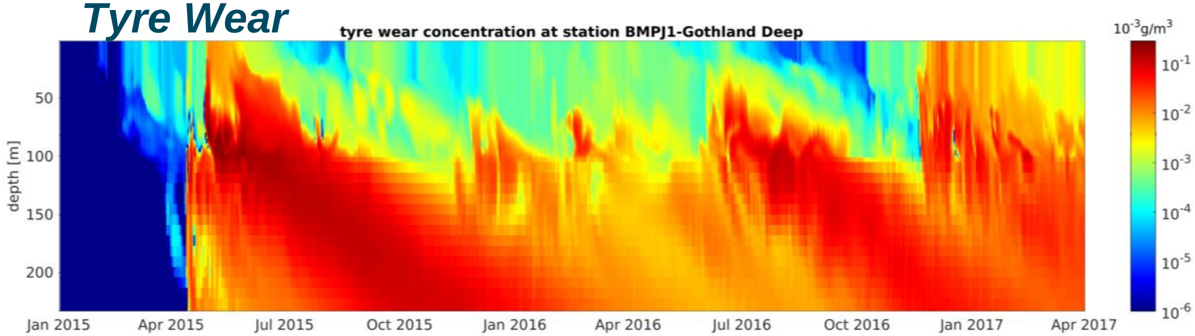
- The concentration of micro plastics in the river runoff is constant in time.
- Consequentially, the mass of micro plastic scales linearily with the river runoff.

River input values for tyre wear and pccp have been derived from the annual mean values in CLAIM D1.2

European Commission | Horizon 2020 European Union funding for Research & Innovation

Vertical tracer dynamic, i.e. sinking or raising of micro plastics

Tyre Wear



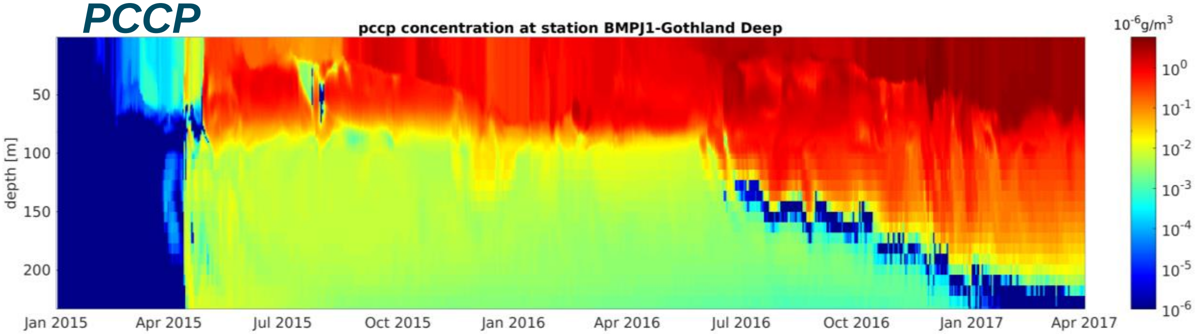
Tyre Wear is heavier than sea water ($\rho_{plastic} > \rho_{water}$) and sinks down to the sea bed.

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.

PCCP



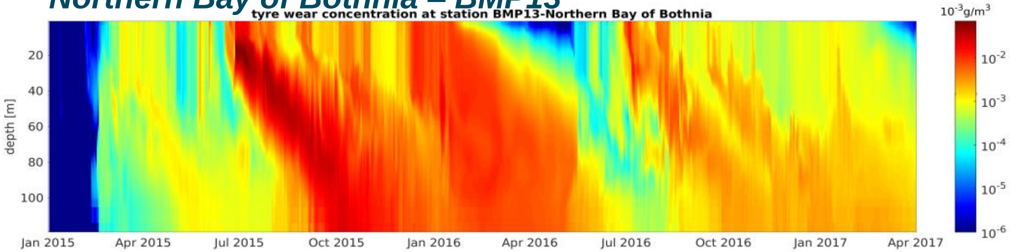
PCCP is lighter than sea water ($\rho_{plastic} > \rho_{water}$) and raises due to his buoyancy to the sea surface.

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

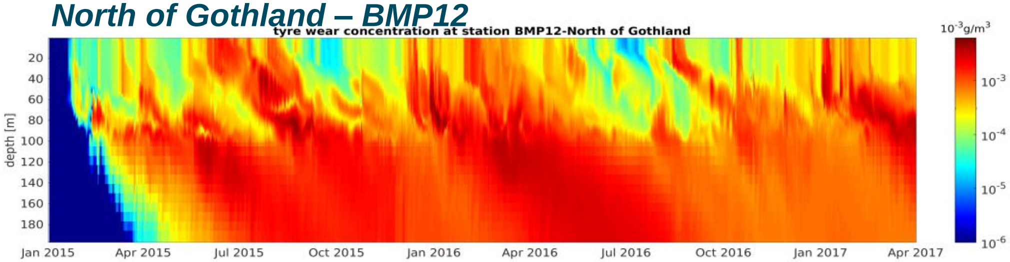
European Commission
Horizon 2020 European Union funding for Research & Innovation

Tyre Wear micro plastics in the Baltic Sea.

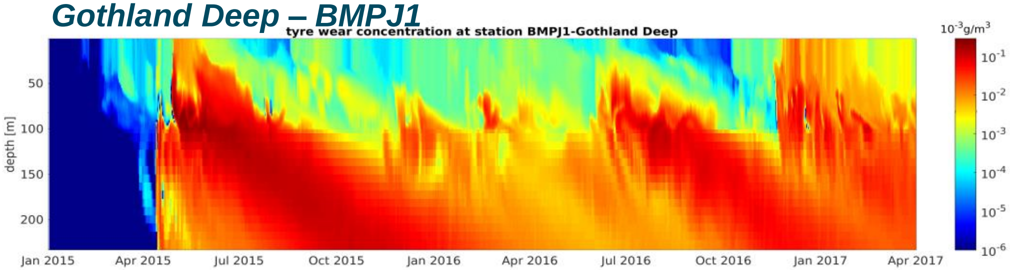
Northern Bay of Bothnia – BMP13



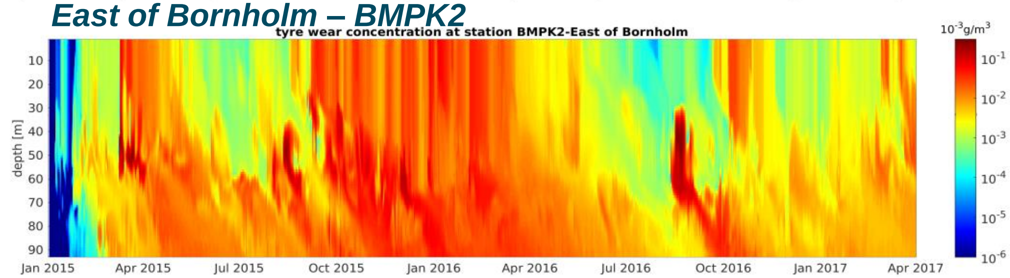
North of Gothland – BMP12



Gothland Deep – BMPJ1

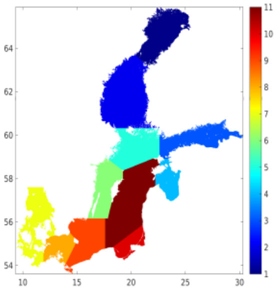


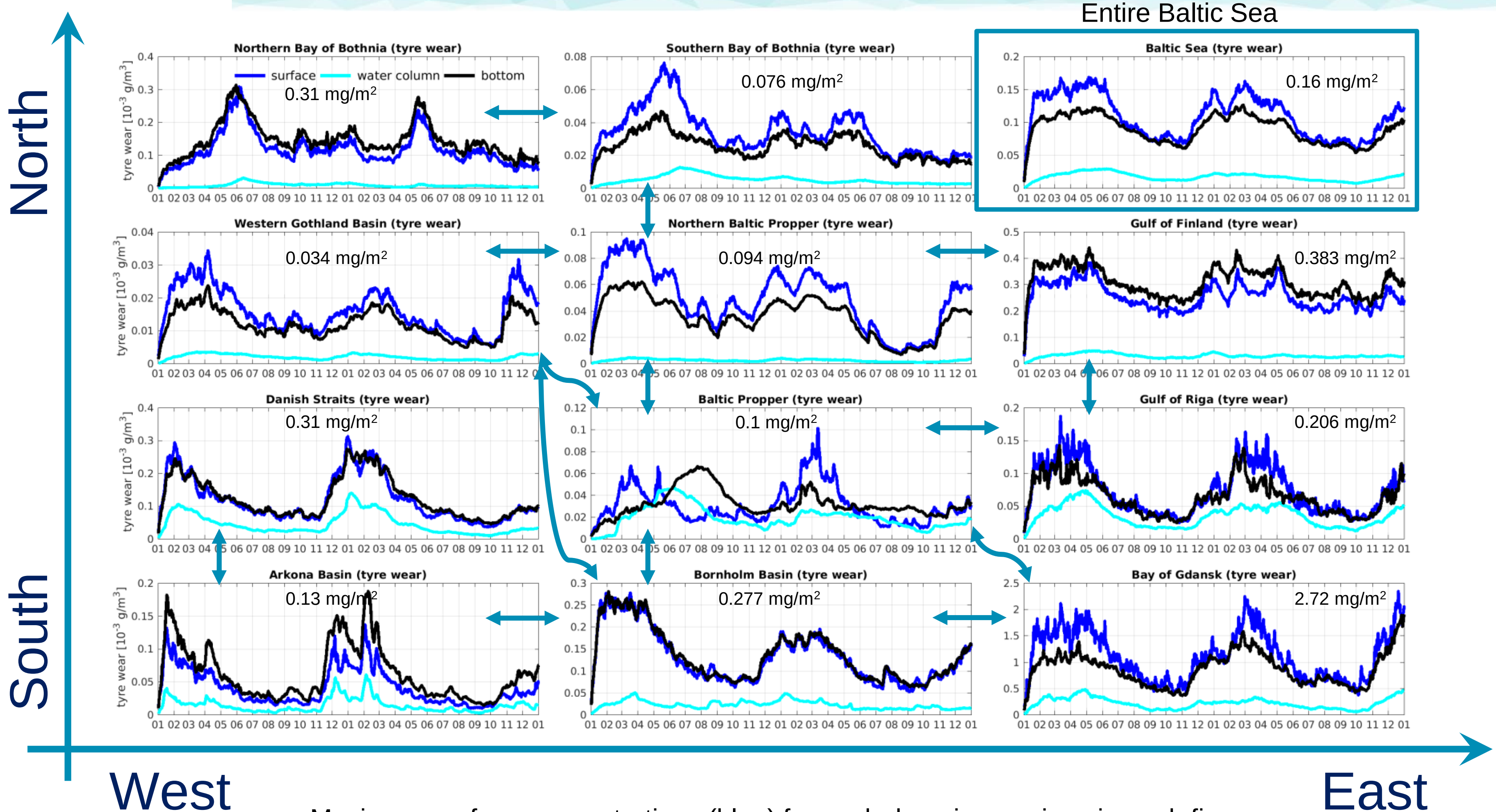
East of Bornholm – BMPK2



- ❑ Micro plastics from Tyre wear is everywhere in the Baltic Sea. It takes only month for it to spread over the entire domain.
- ❑ Tyre wear plastics is heavier than sea water and sinks to the bottom of the Baltic Sea.

Time series of Tyre Wear micro-plastic concentration in the Baltic Sea





Maximum surface concentrations (blue) for each domain are given in each figure.

European Commission
Horizon 2020
European Union funding
for Research & Innovation

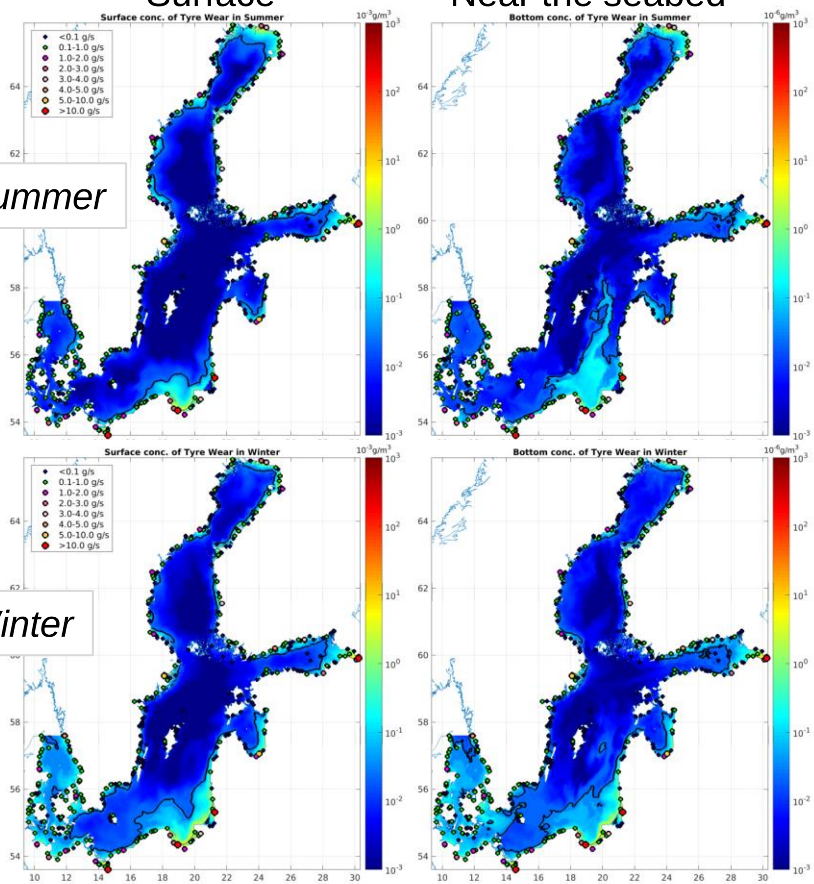
Vertical dynamic of Tyre Wear

CLAIM

Surface | Near the seabed

Summer

Winter



Summer:
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.

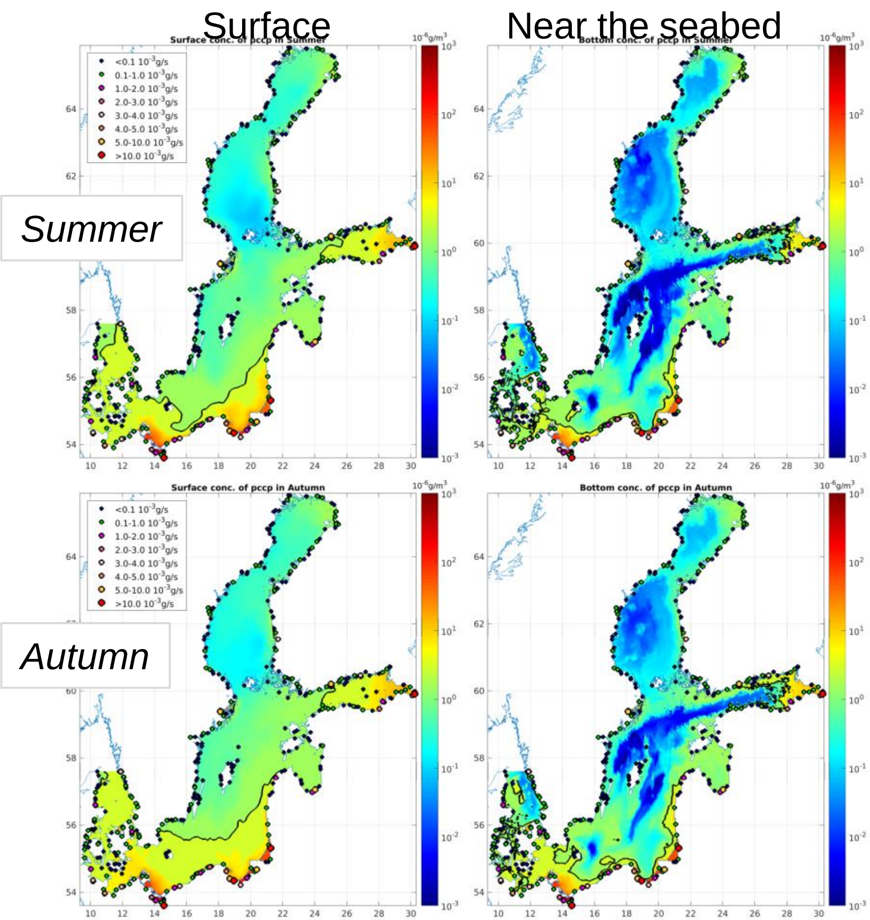
Sedimentation is implemented as a slow removal process

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

Contours mark areas with concentrations larger than $30 \cdot 10^{-6}$ g/m^3

European Commission | Horizon 2020 European Union funding for Research & Innovation

Vertical dynamics of PCCP

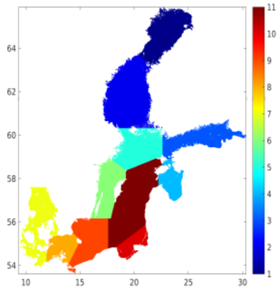


Micro plastic from cosmetic products (PCCP) are lighter than sea water and keep floating, until biofouling increases their density sufficiently enough.

The effect of biofouling has been studied using a simplified model for the biofilm growth.

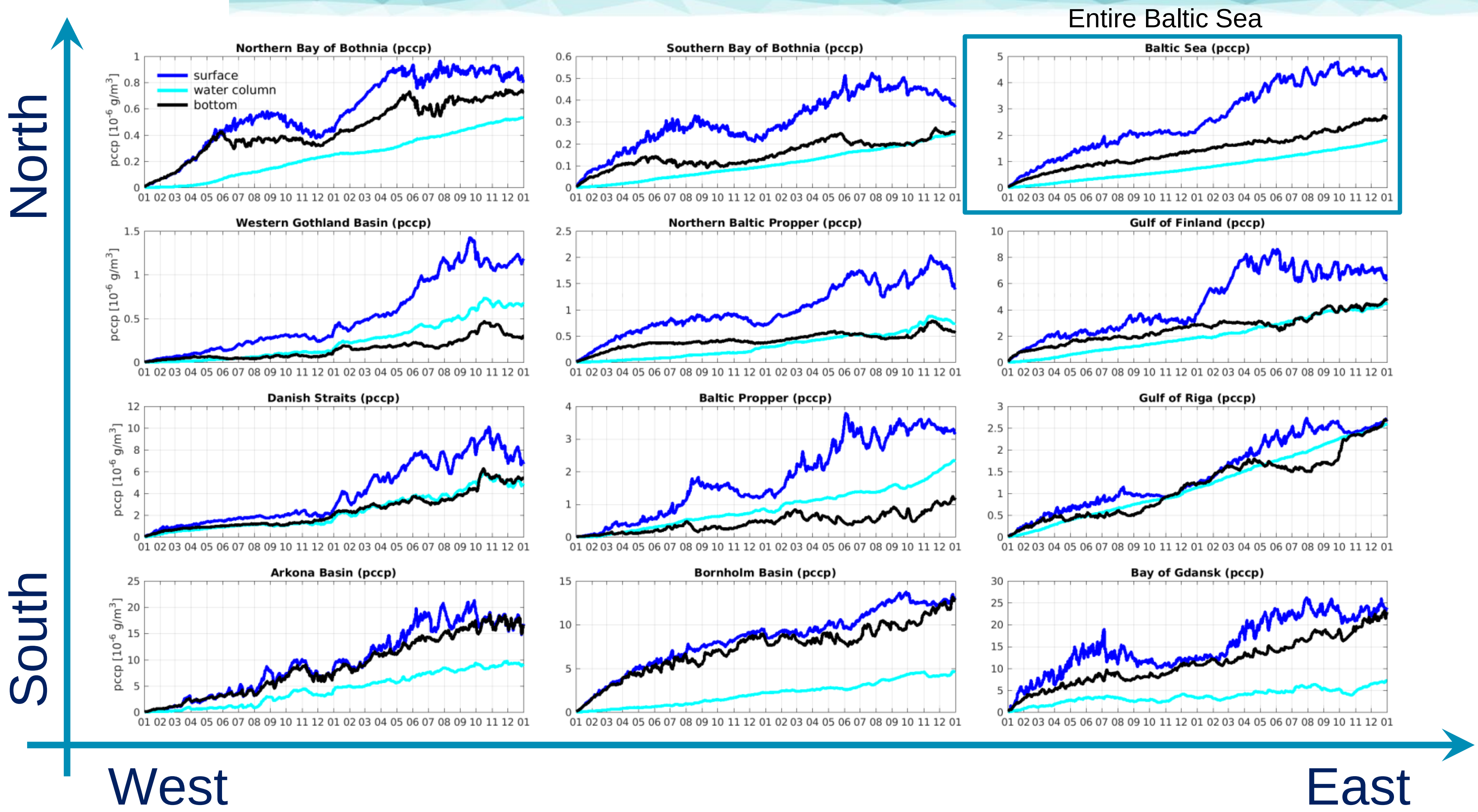
A more comprehensive model for biofouling (Kooi et al 2017) model has been tested as a seperate model. It has not been implemented into HBM yet.

Contours mark areas with concentrations larger than $3 \cdot 10^{-6}$ g/m³



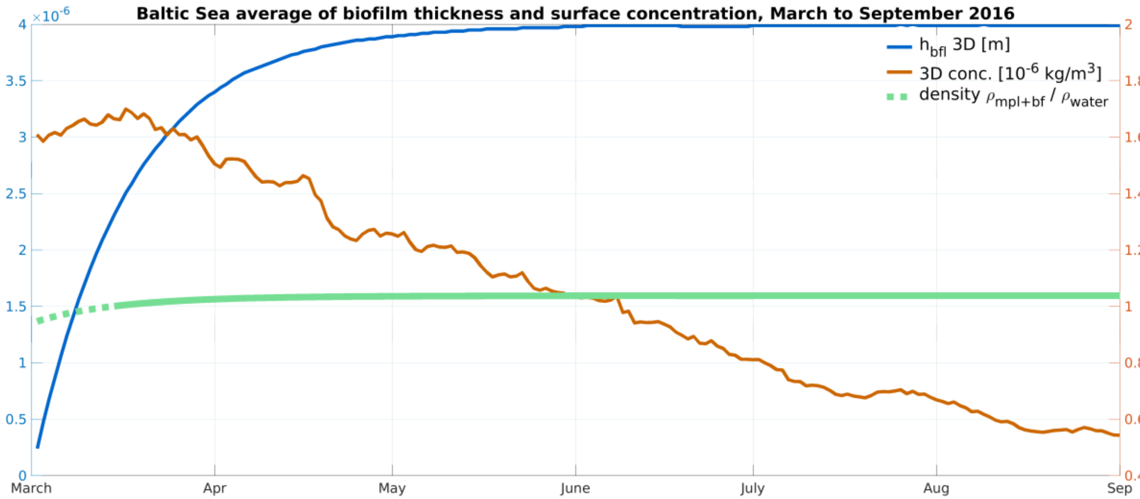
Time series of PCCP micro-plastic concentration in the Baltic Sea

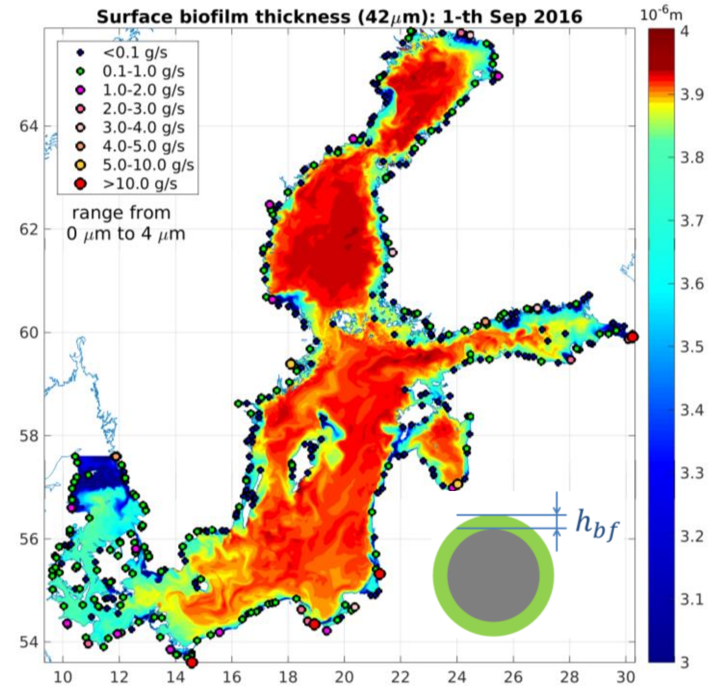
CLAIM



European Commission | Horizon 2020 European Union funding for Research & Innovation

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
- The simplified model does not take into account:
  → encounter and growth of algae in the sea water
  → no seasonality, i.e. light, temperature dependency
  → 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 $h_{max} = 4\mu m$
$T_{sat} = 16.2\ days$

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.

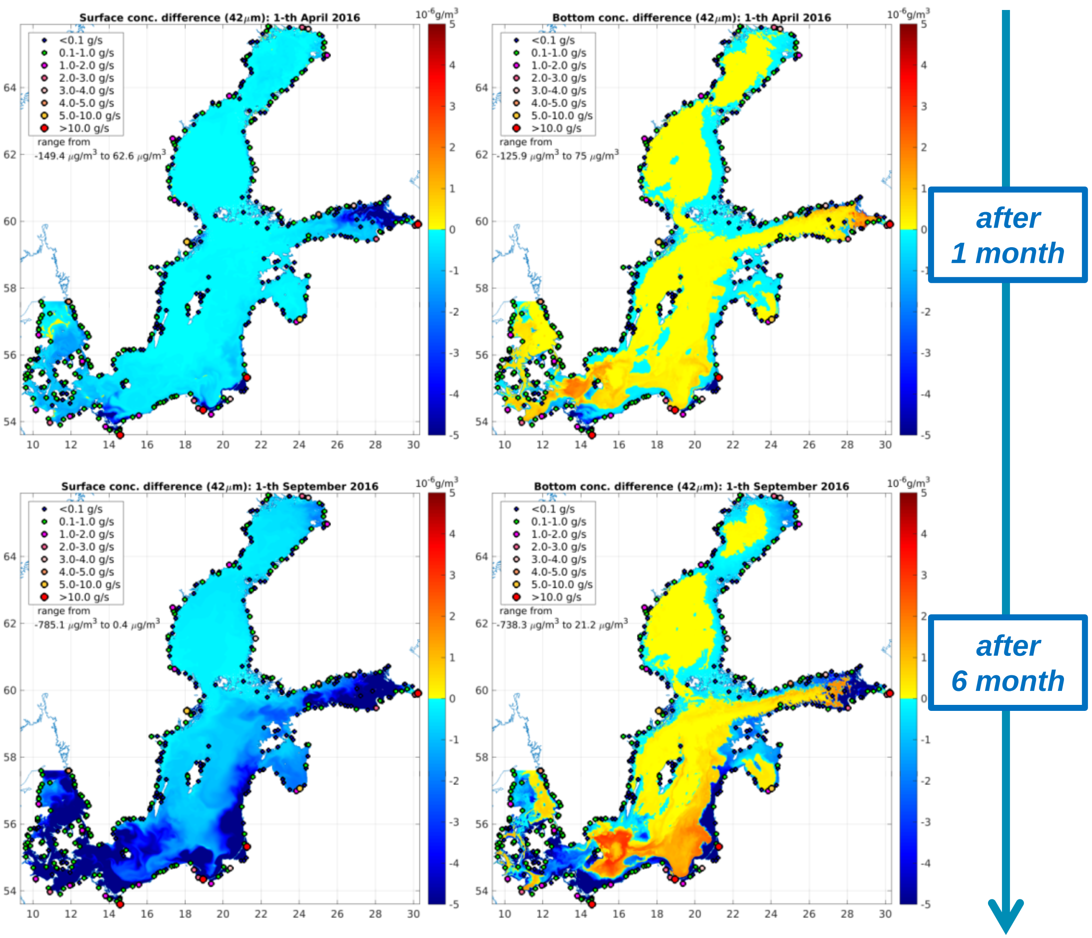
Future steps:

- Implement chl-a dependent growth functions; to include seasonality.
- Derive daily chl-a climatology from CMEMS reanalysis product.

Further down the line:

Implement a biofilm growth model (*Kooi et al 2017*), including

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



European Commission | Horizon 2020 European Union funding for Research & Innovation

Some open questions, currently unresolved processes

Some open questions:

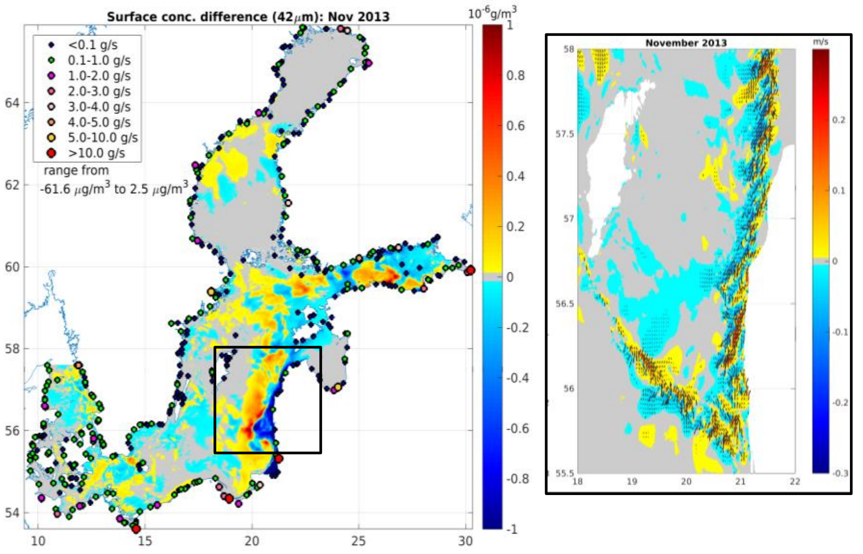
- Mass distribution over size classes for different plastic types. Measurements in WWTP effluents:
  - 15% in size range >300µm (measured at sea)
  - 85% in size range 20µm,…300µm
  - ??% in size range < 20µm (fraction that passes WWTP)
- Seasonally varying micro plastic concentrations, retention in rivers

Currently unresolved processes:

- **Biofouling model**, including the occurrence of algae (either as climatology or as model component)
- **Resuspension/erosion** of sediments and related micro plastic input near the sea bed (wave induced mixing)
- **Wave induced pollutant drift**: 3D implementation, 2-way coupling

Wave induced drift of plastic pollutants

Difference of Monthly mean micro plastic concentration(left) and currents(right), with and without waves.



Initial tests have been performed using a 1-way coupled WAM-HBM model. Waves have been implemented as a driving force to the surface ($F_x = -\nabla_y \cdot S_{xy}$).

European Commission
Horizon 2020 European Union funding for Research & Innovation

CLAIM

Summay

- **Baltic Sea high resolution (926m, horizontally) set-up**, 122 layers (1m resolution in the upper 100m, below the surface). Model Performance has been evaluated at one station in the Gulf of Finland.
- **Micro plastic source mapping for tyre wear, cosmetic products (PCCP)** and laundry wash, including comprehensive literature studies of national source levels and reductions in waste water treatment facilities, as well as river retention (no seasonality).
- **Preliminary study of accumulation zones:** Micro plastic, 2 years hindcast study of tyre wear (heavier than sea water) and PCCP (lighter than sea water).
- **Implementation of a simplified biofouling model**, to increase the density of floating micro plastics and to enable it eventually to sinks to the sea bed.
- **First study of wave induced drift** of micro plastics at sea.

Relevant deliverables

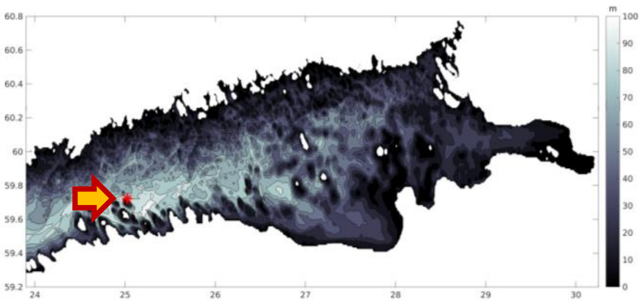
D1.1	A historic observation dataset on visible and invisible plastic litters	
D1.2	Marine plastic litter source dataset in the Baltic and Mediterranean Sea	September 2018
D4.2	Preliminary maps of potential impacts of visible and invisible plastic on ecosystem services	November 2018
D1.3	Innovative forecasting & modelling tools for marine visible and invisible litter pollution	May 2019

European Commission
Horizon 2020
European Union funding
for Research & Innovation

THANK YOU

QUESTIONS?

HBM model verification



Validation station 25º 1.5'E, 59º 43.3'N 25, near Tallin.

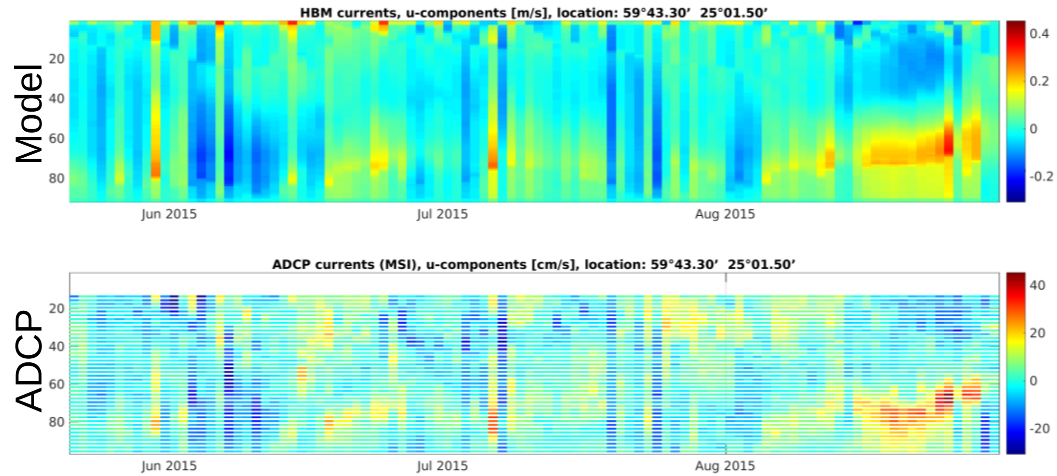
Validation period: medio May to end of August 2015 (Baltic Sea inflow)

Validation of model currents:

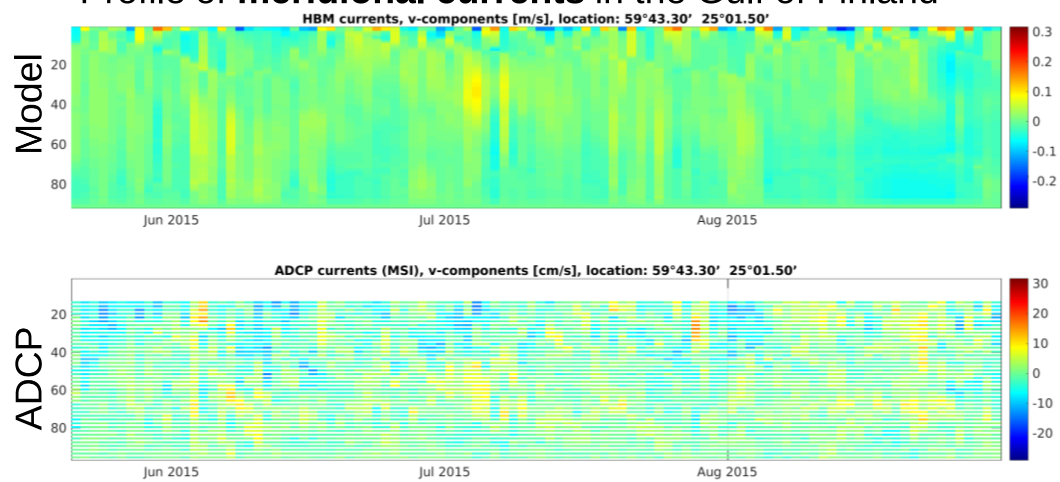
- Near the surface (upper 30m)
  RMSE(u/v): 0.07 **/** 0.05 m/s
  Bias(u/v): 0.03 **/** 0.02 m/s

- Below the surface (>60m):
  RMSE(u/v): 0.04m/s **/** 0.035m/s
  Bias(u/v): 0.01m/s **/** -0.01m/s

Profile of **zonal currents** in the Gulf of Finland

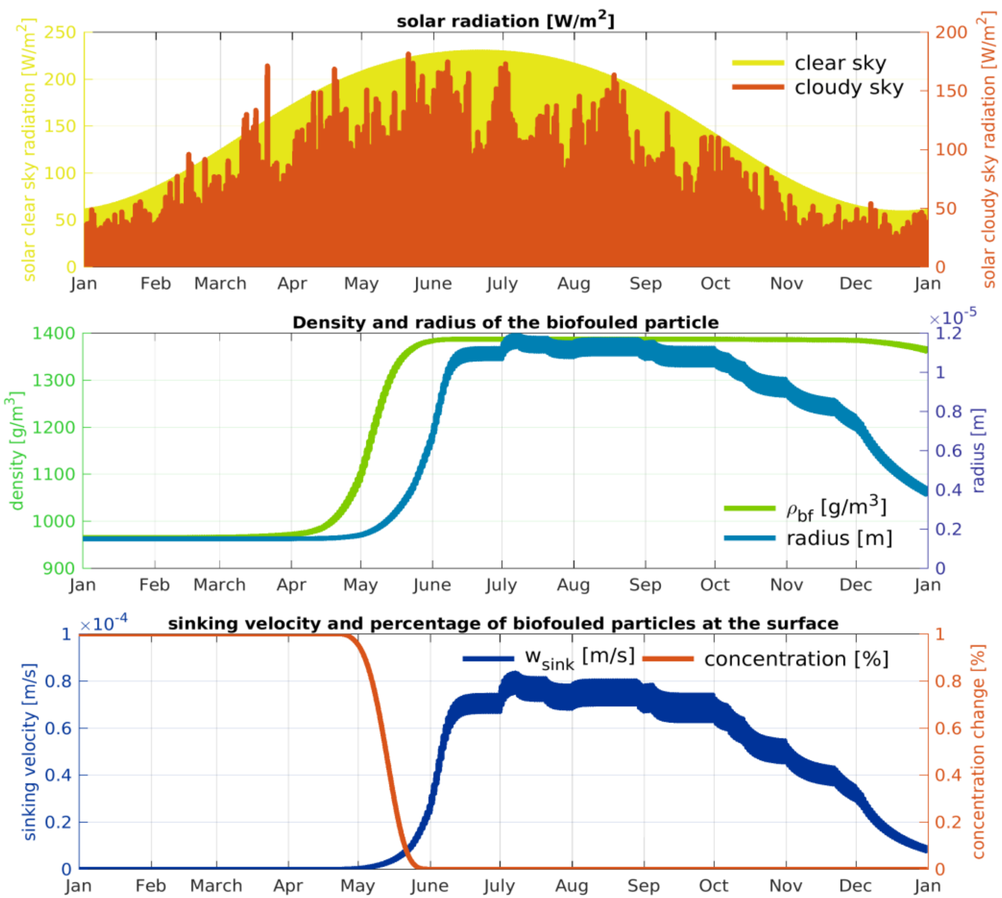


Profile of **meridional currents** in the Gulf of Finland



European Commission
Horizon 2020
European Union funding
for Research & Innovation

Outlook(1):
Parameterisation of Biofouling



Biofouling model at one location in Gothland deep: year 2015

Biofouling as a process to remove small plastic particles (PCCP) from the surface. (Kooi et al 2017)

Number density (A) of algae per surface

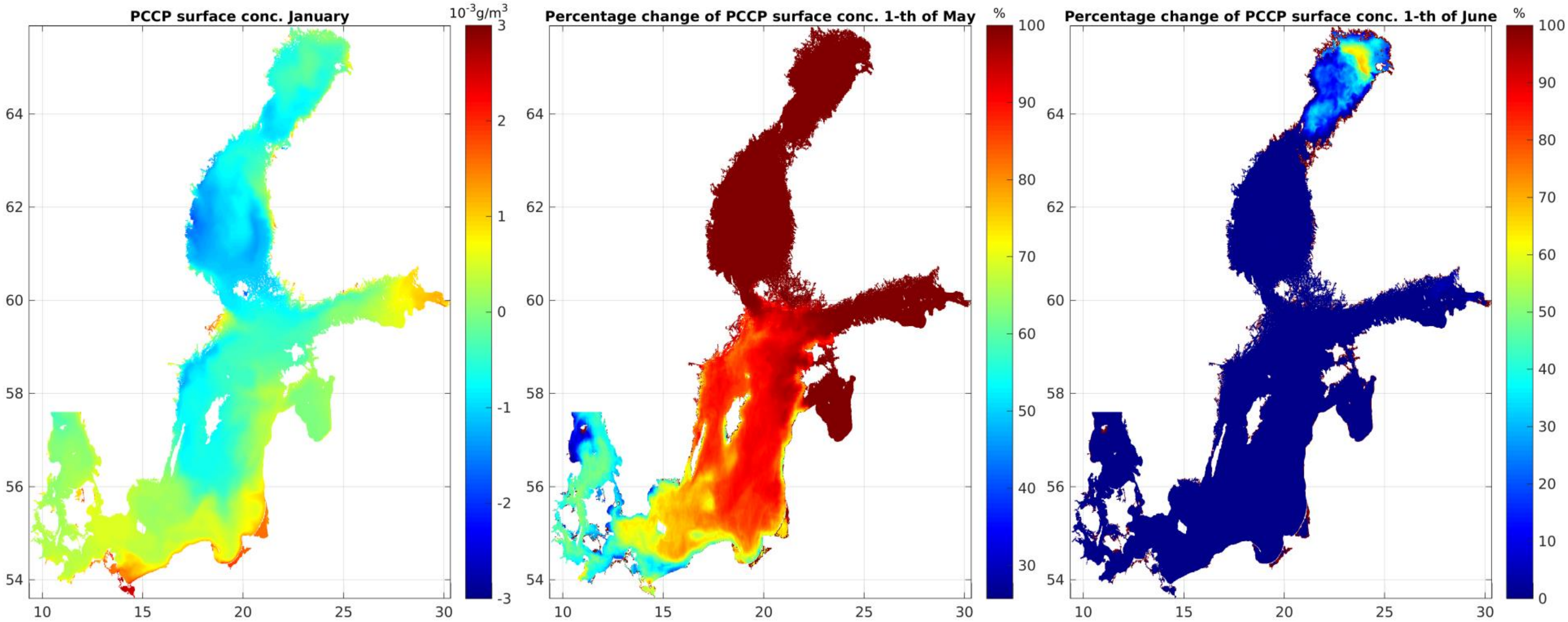
$$\boxed{\frac{dA}{dt} = encounter + growth - grazing - respiration}$$

The model consideres:

a. The encounter of algae along the way up and down the water column
b. The growth of algae (light dependent)
c. Gracing (mortality) of algae
d. Water temp. Dependent respiration

The concentration of algae has been calculated from Chl-A reanalysis concentrations. The conversion factor depends on water temperature and light intensity (PAR).

Biofouling effects on the vertical dynamic

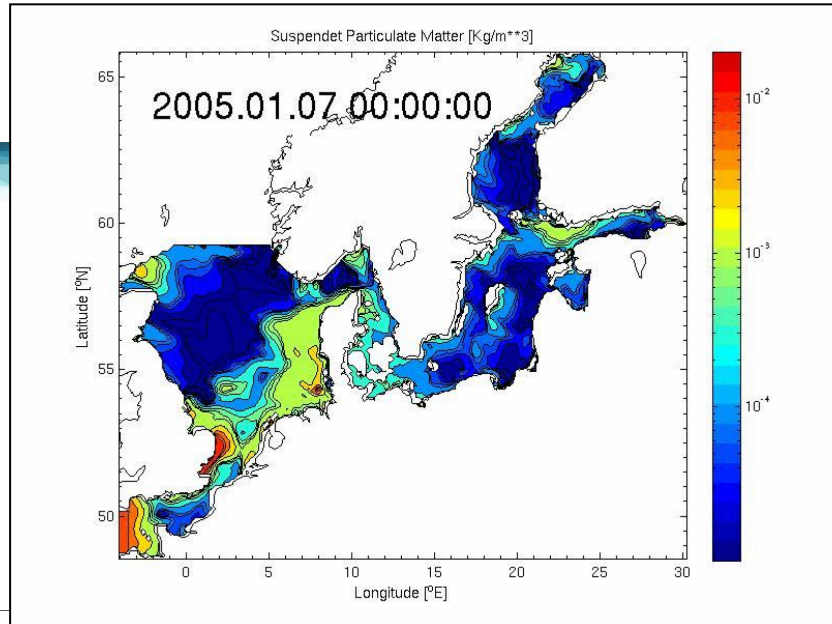


Surface concentration of PCCP in the Baltic Sea (left) and concentration change due to biofouling: 1-th of May (middle) and 1-th of June (right). After 4 month of simulation bioactivity is starting to have an effect on the surface concentration values (middle). Over this time, the radius of plastic-algae particle has become sufficiently large, so that it is fastly removed from the surface.

Outlook(3): Resuspension and upwards mixing

SPM model

3 SPM fractions:
$w_{sink}(f_1)=0.0001$ m/s
$w_{sink}(f_2)=0.00002$ m/s
$w_{sink}(f_3)=0.001$ m/s



Processes:
- *Sinking versus mixing*
- *Advection*
- *Sedimentation*
- *Re-suspension*
- *Erosion*
- *Consumption*
- *Bioturbation*