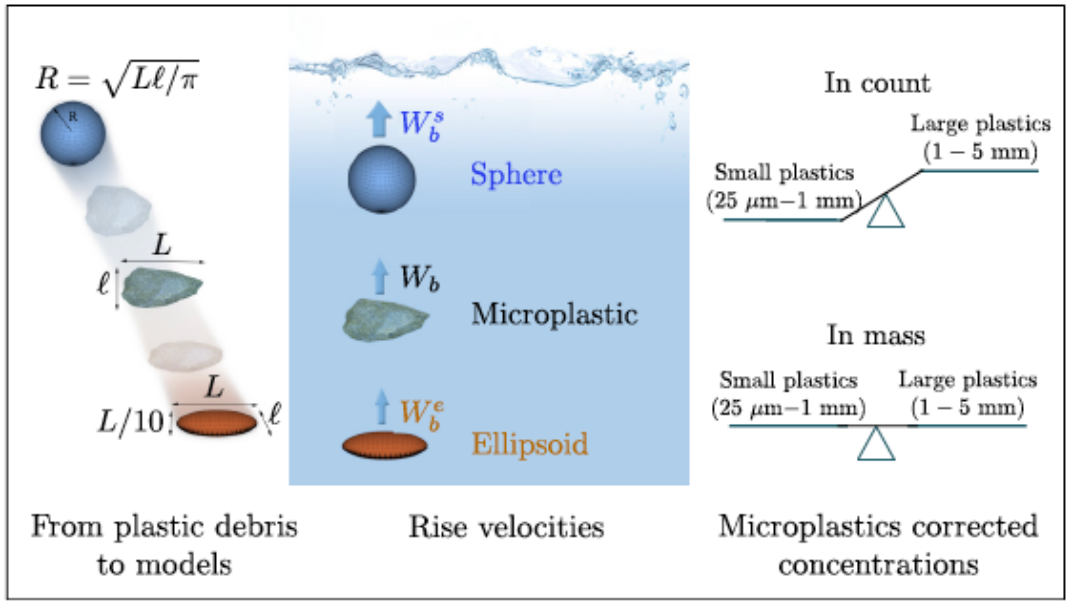
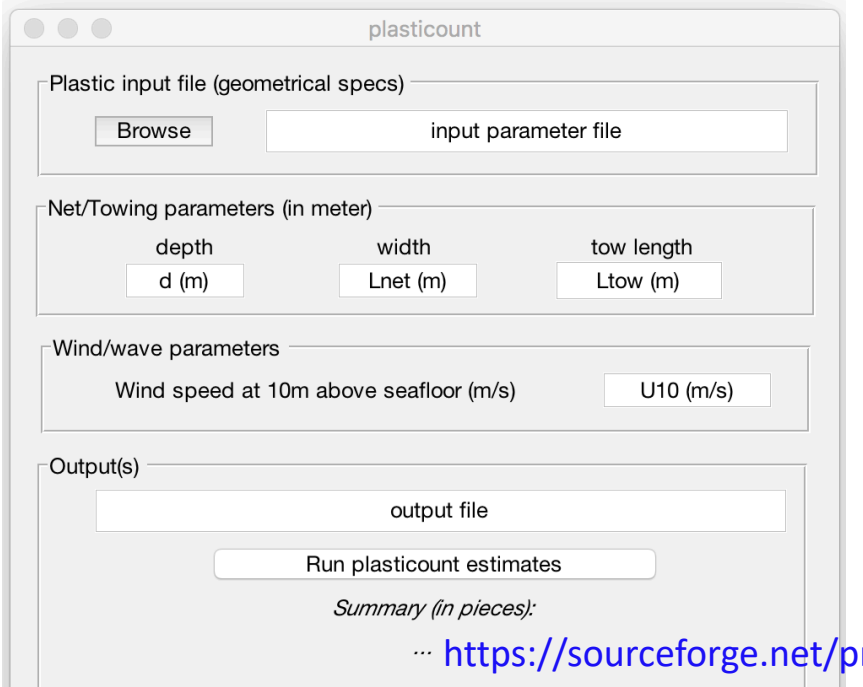
Uncertainties on plastic concentration estimates at sea

Matthieu Mercier (IMFT, France)
Marie Poulain-Zarcos (IMFT-IMRCP, France)
Alexandra ter Halle (IMRCP, France)
Florian Simatos (ISAE, France)
Marion Saint-Martin (*stagiaire* IMFT, France)

https://doi.org/10.1021/acs.est.8b05458



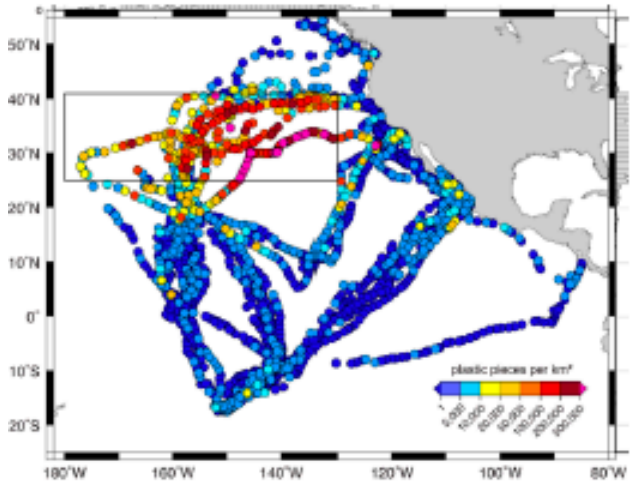
Poulain et al., Environ. Sci. Technol. 2019, 53, 3, 1157-1164



··· https://sourceforge.net/projects/plasticount/

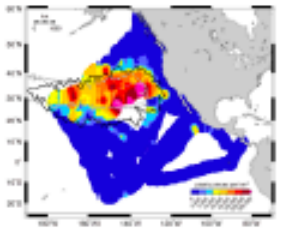
EGU 2021, online, 26-30/04/2021

Motivations: from field measurements to global estimates

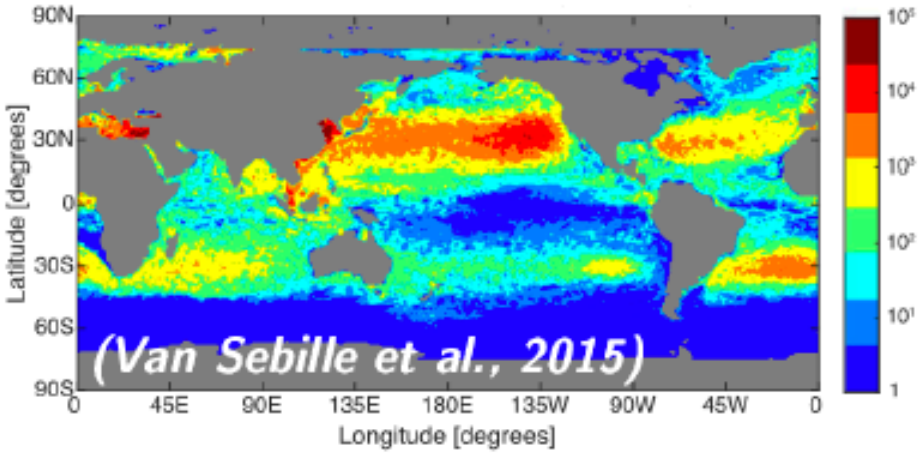


(Law et al., 2014)

Inputs (with/without smoothing) for model's adjustments

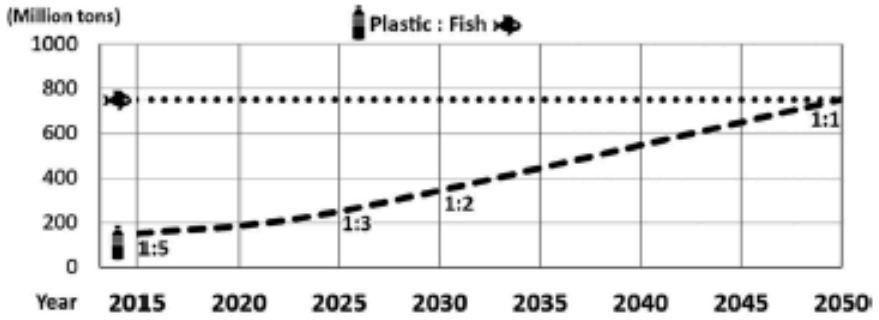


Between 0.093 and 0.236 Mtons in total



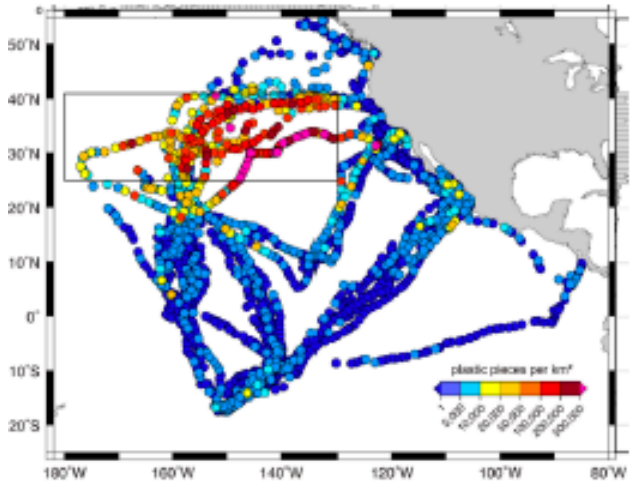
mismatch

~15 Mtons /year entering the oceans



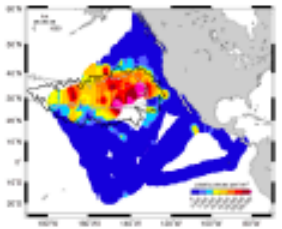
(Crawford & Quinn, 2017)

Motivations: from field measurements to global estimates

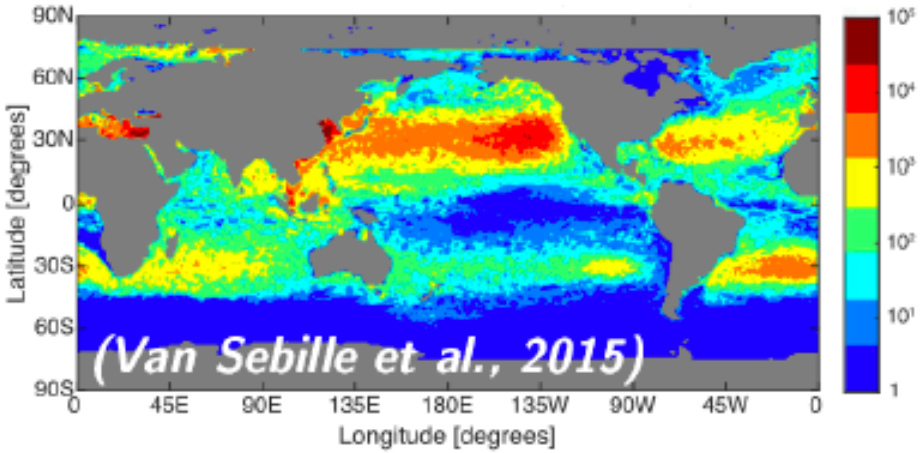


(Law et al., 2014)

Inputs (with/without smoothing) for model's adjustments

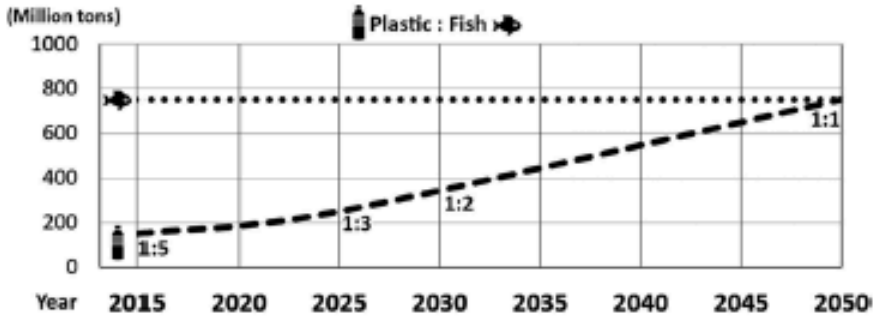


Between 0.093 and 0.236 Mtons in total



mismatch

~15 Mtons /year entering the oceans



(Crawford & Quinn, 2017)

Commonly said that we find back only ~1% of what is incoming…

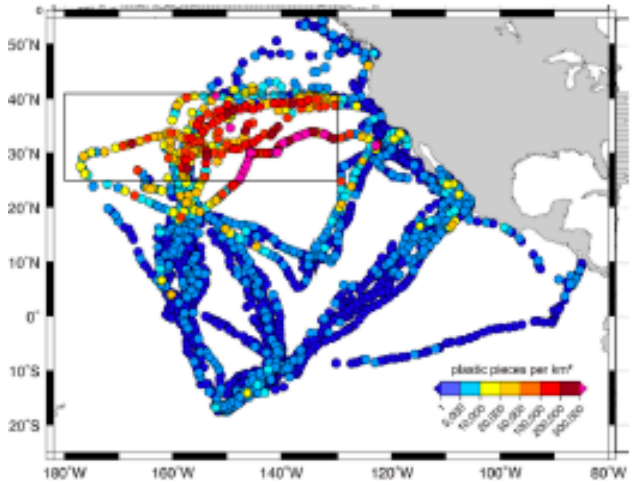
Where is the rest ?

Actually, field measurements play a very strong part here. Our approach today is to discuss:

What confidence we have in field measurements ?

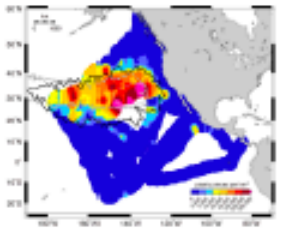
How to provide relevant error bounds on the 1% estimate ?

Motivations: from field measurements to global estimates

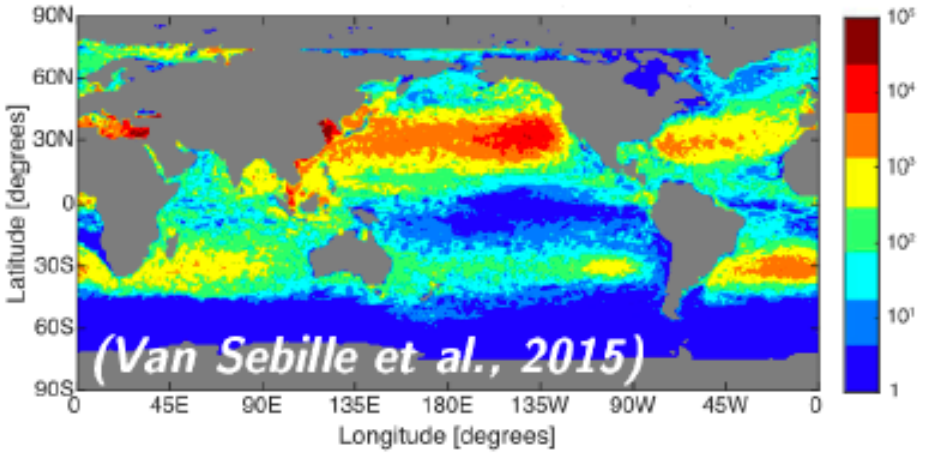


(Law et al., 2014)

Inputs (with/without smoothing) for model's adjustments

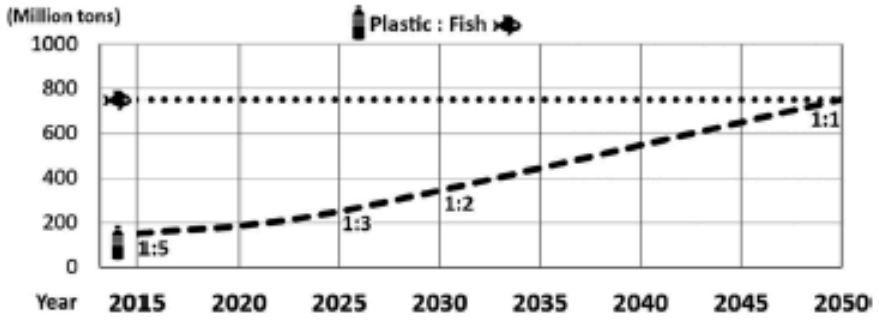


Between 0.093 and 0.236 Mtons in total



mismatch

~15 Mtons /year entering the oceans



(Crawford & Quinn, 2017)

Commonly said that we find back only ~1% of what is incoming…

Where is the rest ?

Actually, field measurements play a very strong part here. Our approach today is to discuss:

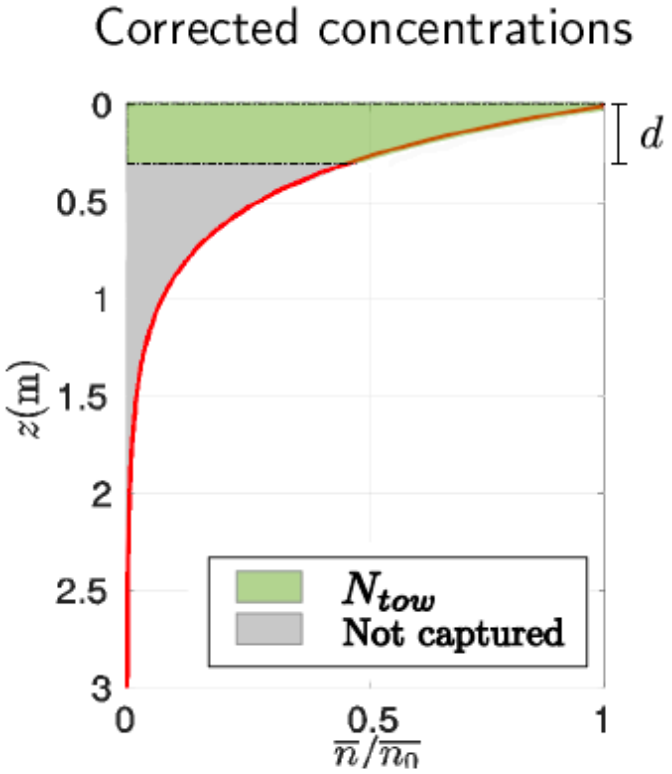
What confidence we have in field measurements ?

How to provide relevant error bounds on the 1% estimate ?

Focus 1: Field measurement estimates

Focus 2: Implications of model on microplastics at sea

1.1. Model for field measurements (sea-surface) estimates

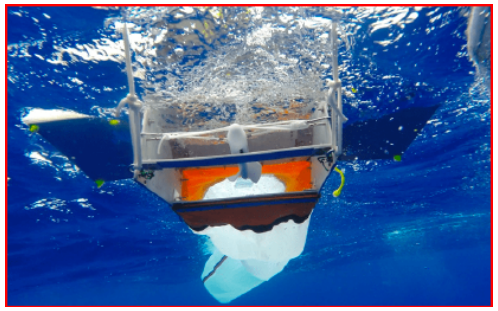


$$\overline{n} = \overline{n_0}\exp(zW_b/A_0)$$

$\overline{n_0} = \overline{n}(z = 0)$
W_b : rise velocity
A_0 : turbulent parameter

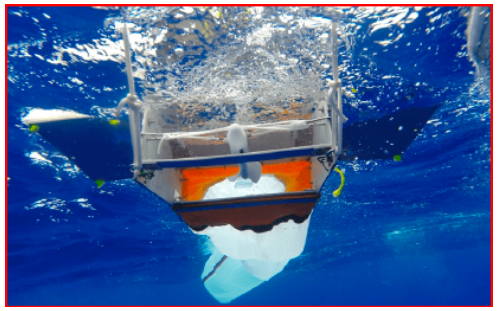
(Kukulka et al., 2012)

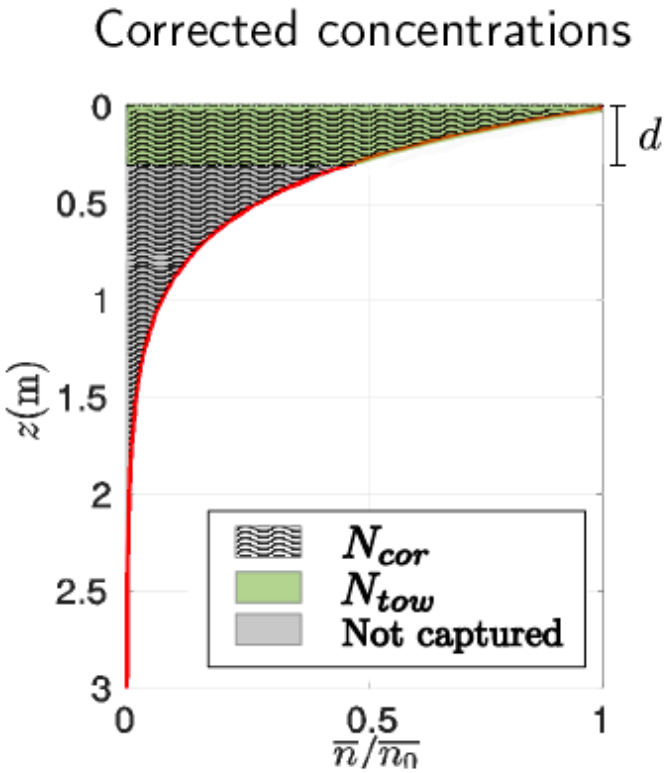
manta net towing



1.1. Model for field measurements (sea-surface) estimates

manta net towing





$$\overline{n} = \overline{n_0}\exp(zW_b/A_0)$$

$\overline{n_0} = \overline{n}(z=0)$
W_b : rise velocity
A_0 : turbulent parameter

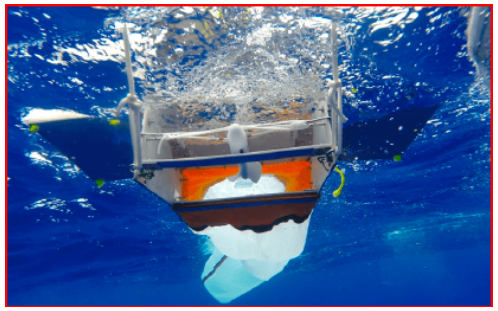
$$N_{cor} = \frac{N_{tow}}{1-\exp\left(d\frac{W_b}{A_0}\right)}$$

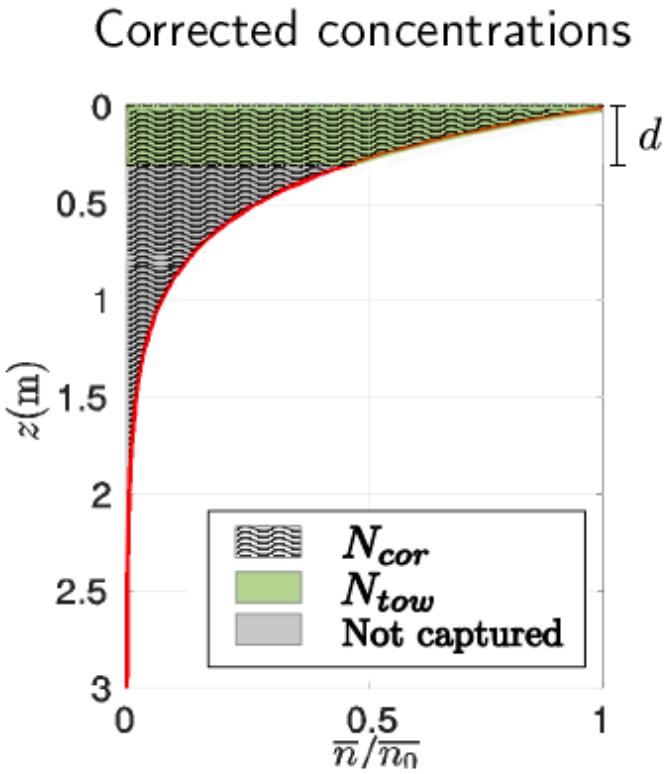
(Kukulka et al., 2012)

→ N_{cor} (modeled estimate) strongly depends on W_b (rise velocity) and A_0 (sea-state turbulent diffusivity)

1.1. Model for field measurements (sea-surface) estimates

manta net towing





$$\overline{n} = \overline{n_0}\exp(zW_b/A_0)$$

$\overline{n_0} = \overline{n}(z=0)$
W_b : rise velocity
A_0 : turbulent parameter

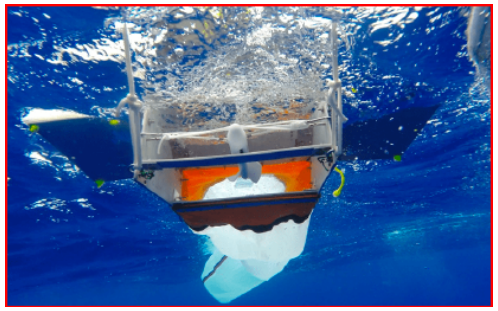
$$N_{cor} = \frac{N_{tow}}{1-\exp\left(d\frac{W_b}{A_0}\right)}$$

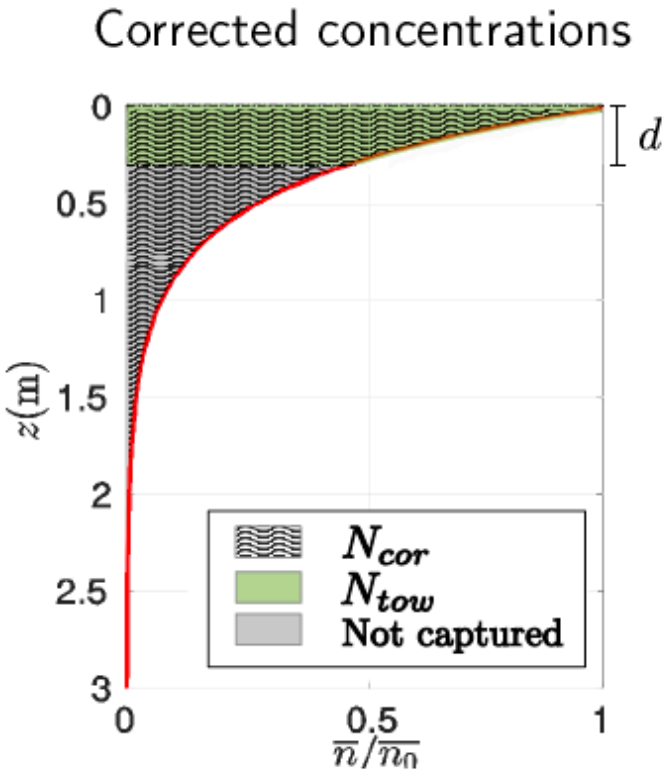
(Kukulka et al., 2012)

→ N_{cor} (modeled estimate) strongly depends on W_b (rise velocity) and A_0 (sea-state turbulent diffusivity)
- A_0 (usually) considered constant with depth

1.1. Model for field measurements (sea-surface) estimates

manta net towing





$$\overline{n} = \overline{n_0}\exp(zW_b/A_0)$$

$\overline{n_0} = \overline{n}(z=0)$
W_b : rise velocity
A_0 : turbulent parameter

$$N_{cor} = \frac{N_{tow}}{1-\exp\left(d\frac{W_b}{A_0}\right)}$$

(Kukulka et al., 2012)

→ N_{cor} (modeled estimate) strongly depends on W_b (rise velocity) and A_0 (sea-state turbulent diffusivity)

- A_0 (usually) considered constant with depth
- W_b depends on the plastic properties

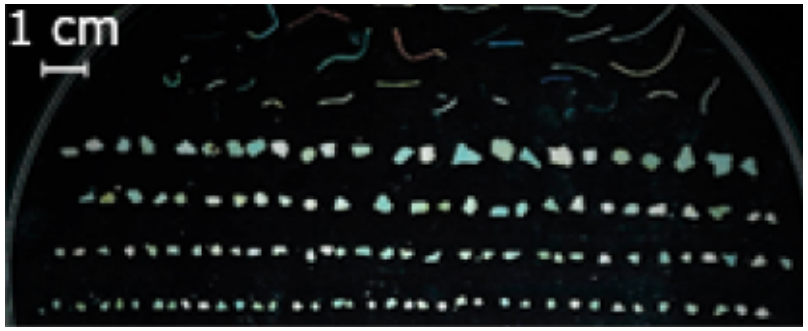
1.2. New approach for W_b based on plastic samples analysis

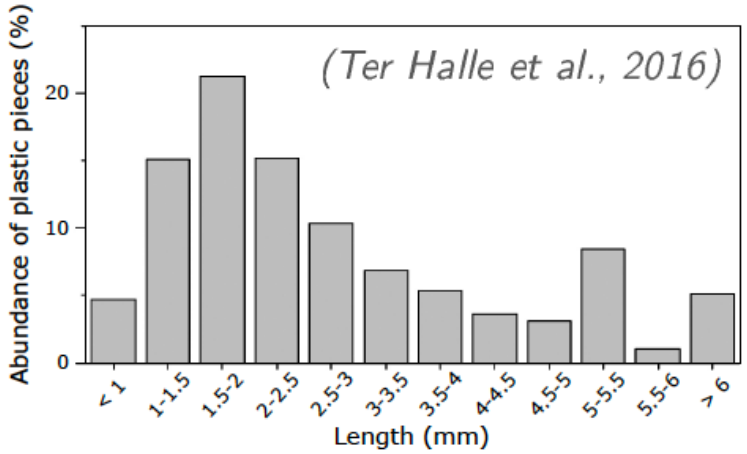
LMP : large microplastics
(1mm < L < 5mm)
SMP: small microplastics
(25µm < L < 1mm)

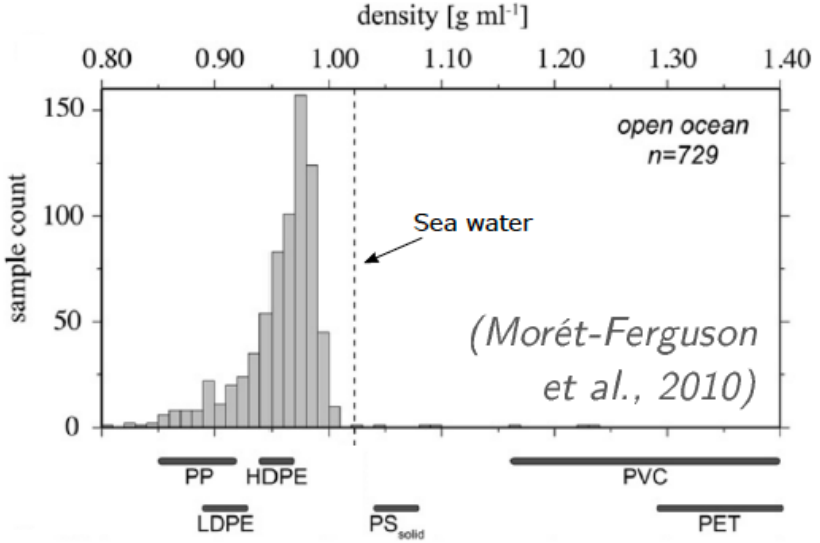
1.2. New approach for W_b based on plastic samples analysis

LMP : large microplastics
(1mm < L < 5mm)
SMP: small microplastics
(25µm < L < 1mm)

- Small plastic particles come in a great diversity of shape, size and density



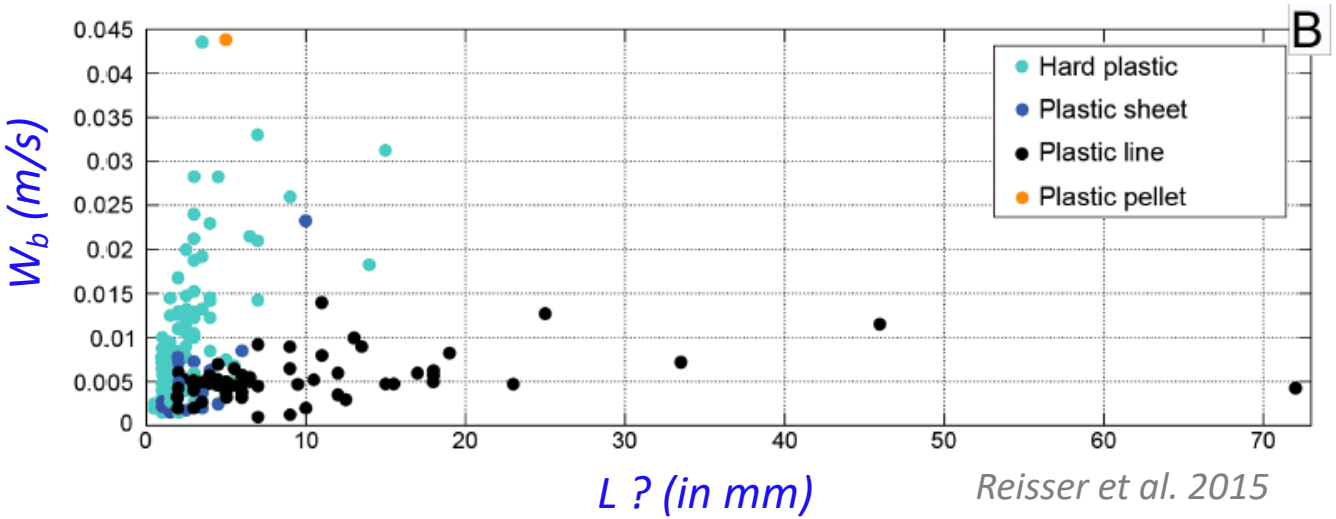




1.2. New approach for W_b based on plastic samples analysis

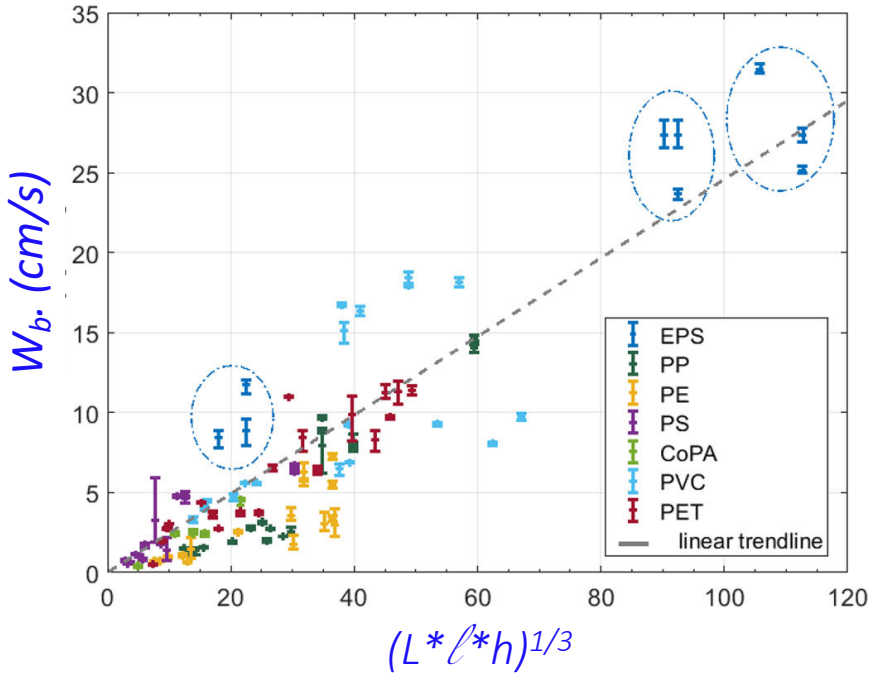
LMP : large microplastics (1mm < L < 5mm)
SMP: small microplastics (25µm < L < 1mm)

- Small plastic particles come in a great diversity of shape, size and density
- Previous models for W_b were based on a ***mean*** value only, although a great diversity is observed…
  - W_b=0.01 m/s for all plastic (*Kukulka et al. 2012; Reisser et al. 2015*)
  - $W_b(L)$ with a sphere model for all plastic (*Enders et al. 2015*)
  - $W_b(L,\ell,h)$ for bluff bodies (*Waldschläger & Schüttrump 2019*)



Reisser et al. 2015

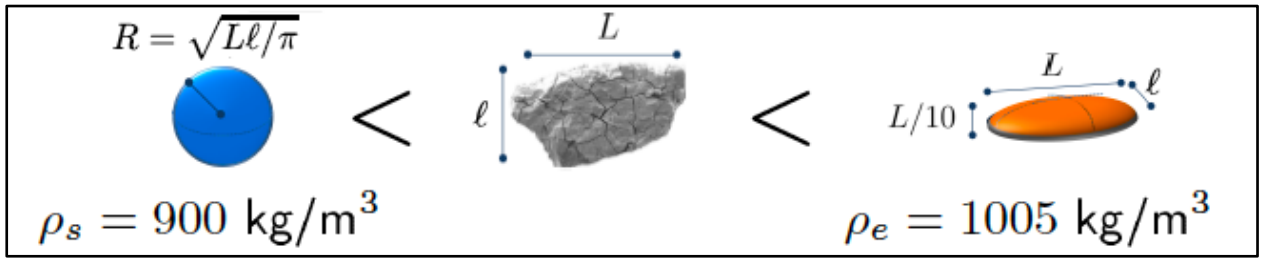
(*Waldschläger & Schüttrump 2019*)



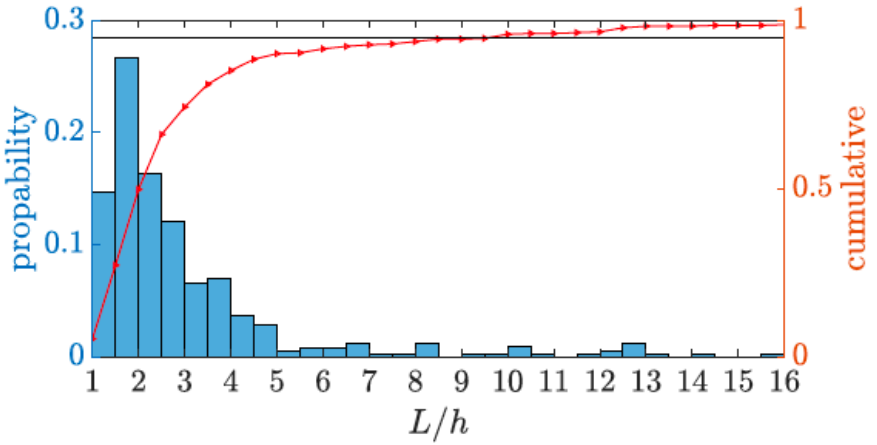
1.2. New approach for W_b based on plastic samples analysis

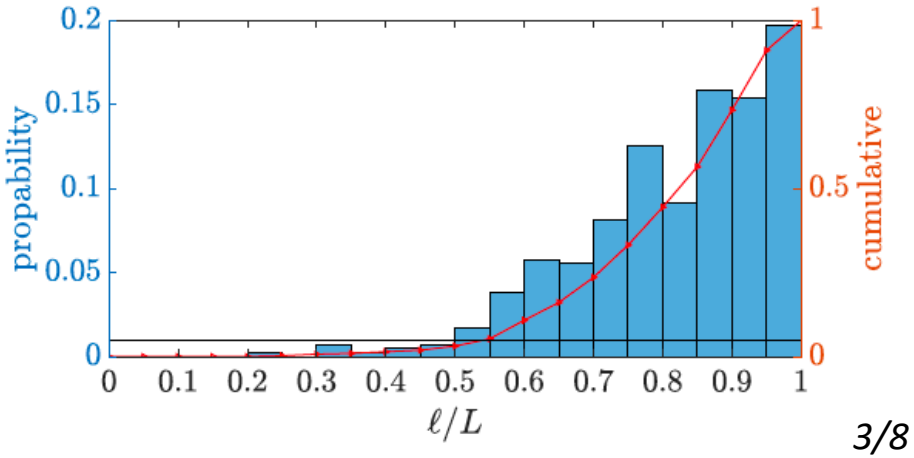
LMP : large microplastics (1mm < L < 5mm)
SMP: small microplastics (25µm < L < 1mm)

- Small plastic particles come in a great diversity of shape, size and density
- Previous models for W_b were based on a ***mean*** value only, although a great diversity is observed…
- Our approach is based on **encompassing values (two models, sphere/ellipsoid)**



Choice of the models based on the study of ~400 samples collected in the North Atlantic gyre (NGO expedition 7th Continent)

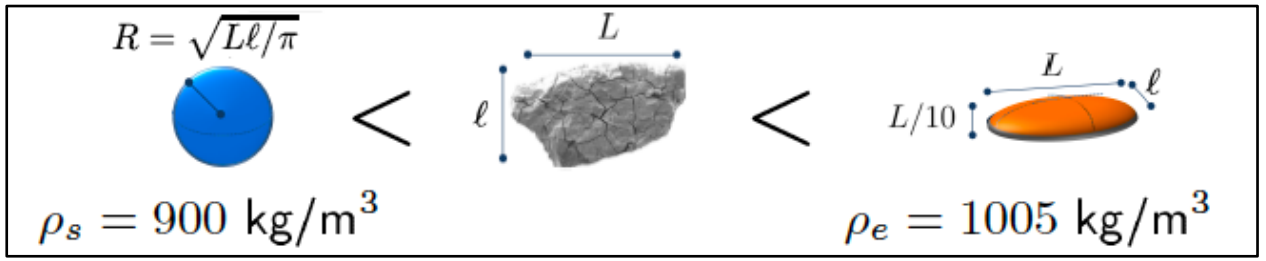




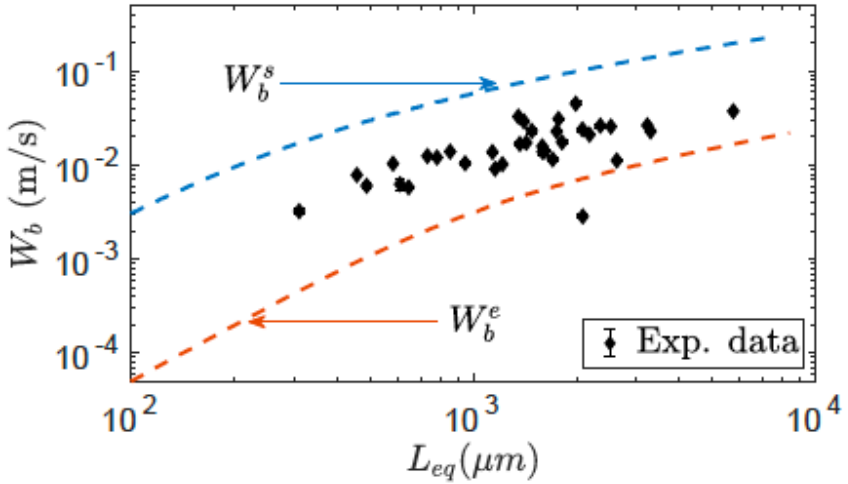
1.2. New approach for W_b based on plastic samples analysis

LMP : large microplastics (1mm < L < 5mm)
SMP: small microplastics (25µm < L < 1mm)

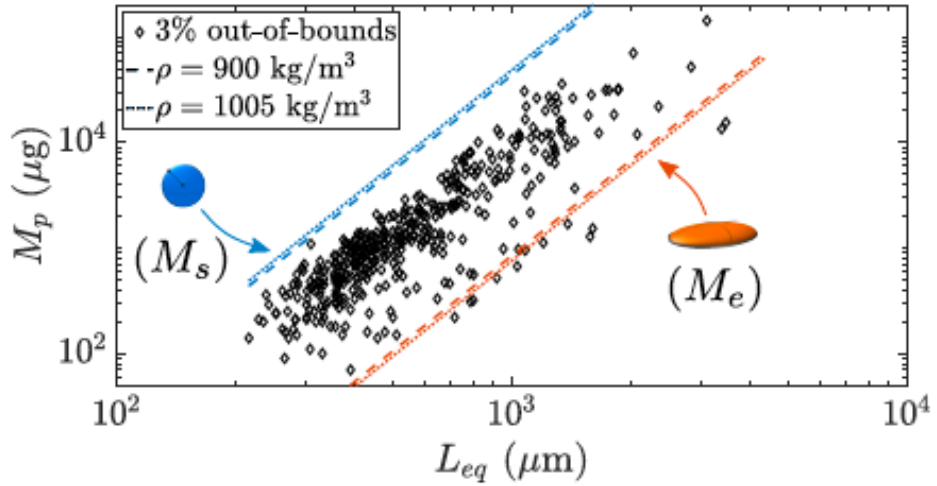
- Small plastic particles come in a great diversity of shape, size and density
- Previous models for W_b were based on a ***mean*** value only, although a great diversity is observed…
- Our approach is based on **encompassing values (two models, sphere/ellipsoid)**



Validation of the models based on velocity and mass measurements



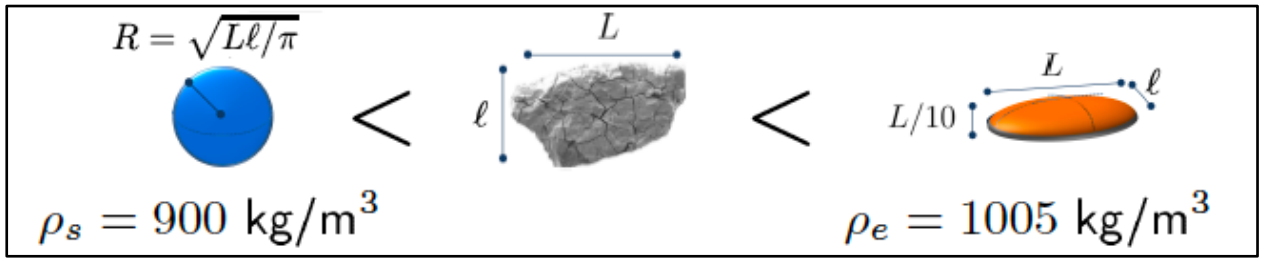
$$L_{eq} = \frac{\sqrt{L\ell}}{2}$$



1.2. New approach for W_b based on plastic samples analysis

LMP : large microplastics (1mm < L < 5mm)
SMP: small microplastics (25µm < L < 1mm)

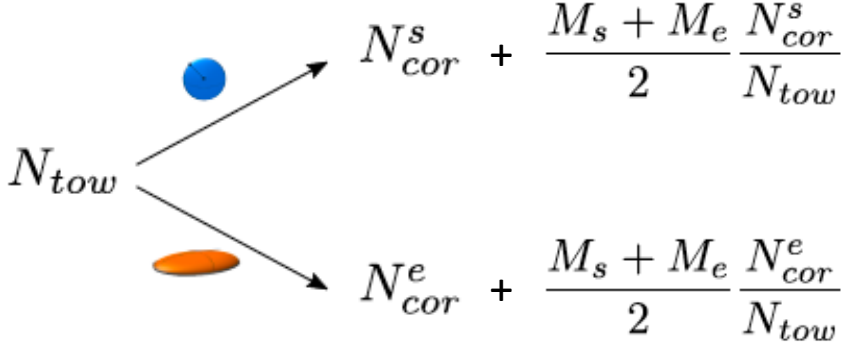
- Small plastic particles come in a great diversity of shape, size and density
- Previous models for W_b were based on a ***mean*** value only, although a great diversity is observed…
- Our approach is based on **encompassing values (two models, sphere/ellipsoid)**



For each sample (knowing its two largest dimensions to have $L_{eq} = \frac{\sqrt{L\ell}}{2}$), we predict **encompassing concentration estimates** both

in number $N_{cor}^s < N_{cor} < N_{cor}^e$

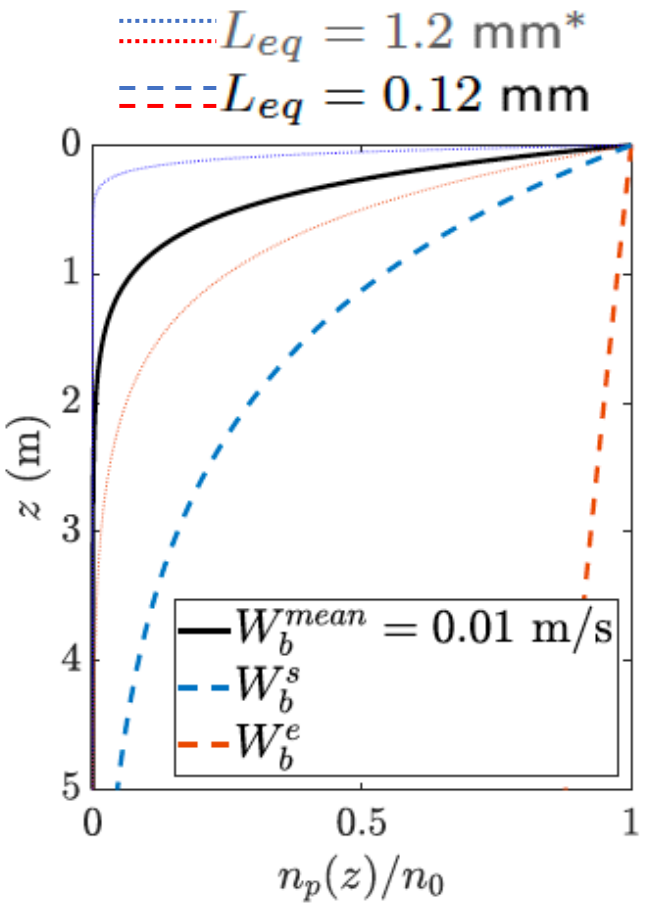
and in mass $M_{cor}^s < M_{cor} < M_{cor}^e$



2.1. Implication for microplastics estimates (general)

LMP : large microplastics
(1mm < L < 5mm)
SMP: small microplastics
(25µm < L < 1mm)

- Model for LMP is in agreement with past (mean) estimates, but SMP concentrations were underestimated...



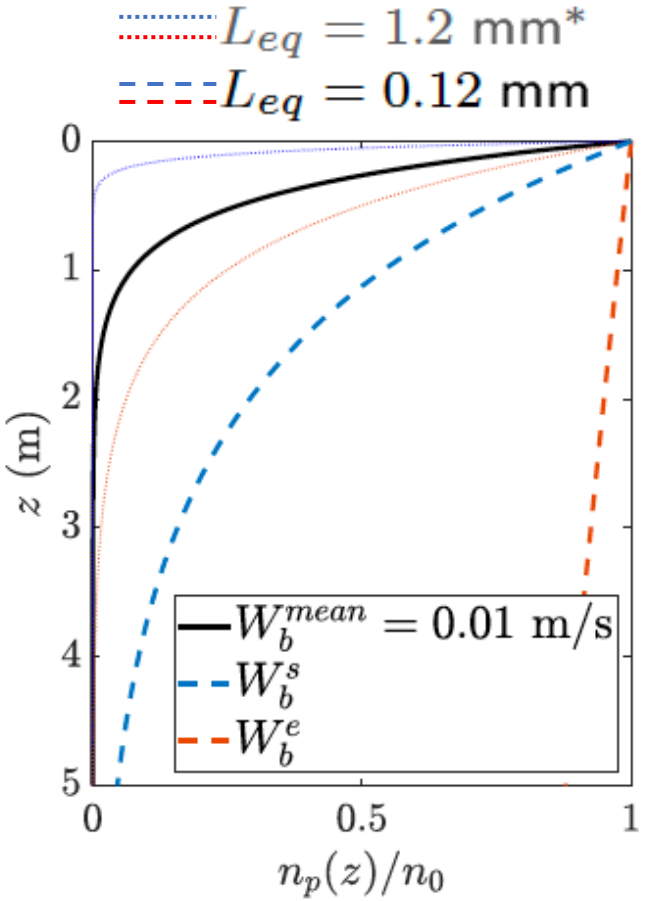
$$n_p(z) = n_0 \exp(-zW_b/A_0)$$

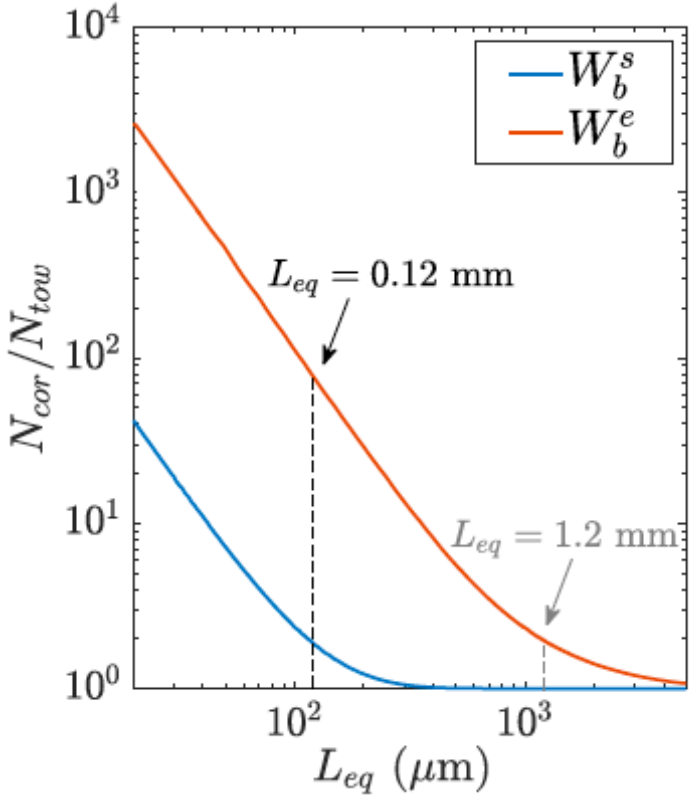
2.1. Implication for microplastics estimates (general)

LMP : large microplastics
(1mm < L < 5mm)
SMP: small microplastics
(25µm < L < 1mm)

- Model for LMP is in agreement with past (mean) estimates, but SMP concentrations were underestimated...

  … SMP surface measurements are a small fraction of the total (a few percents) … even less at Beaufort >2



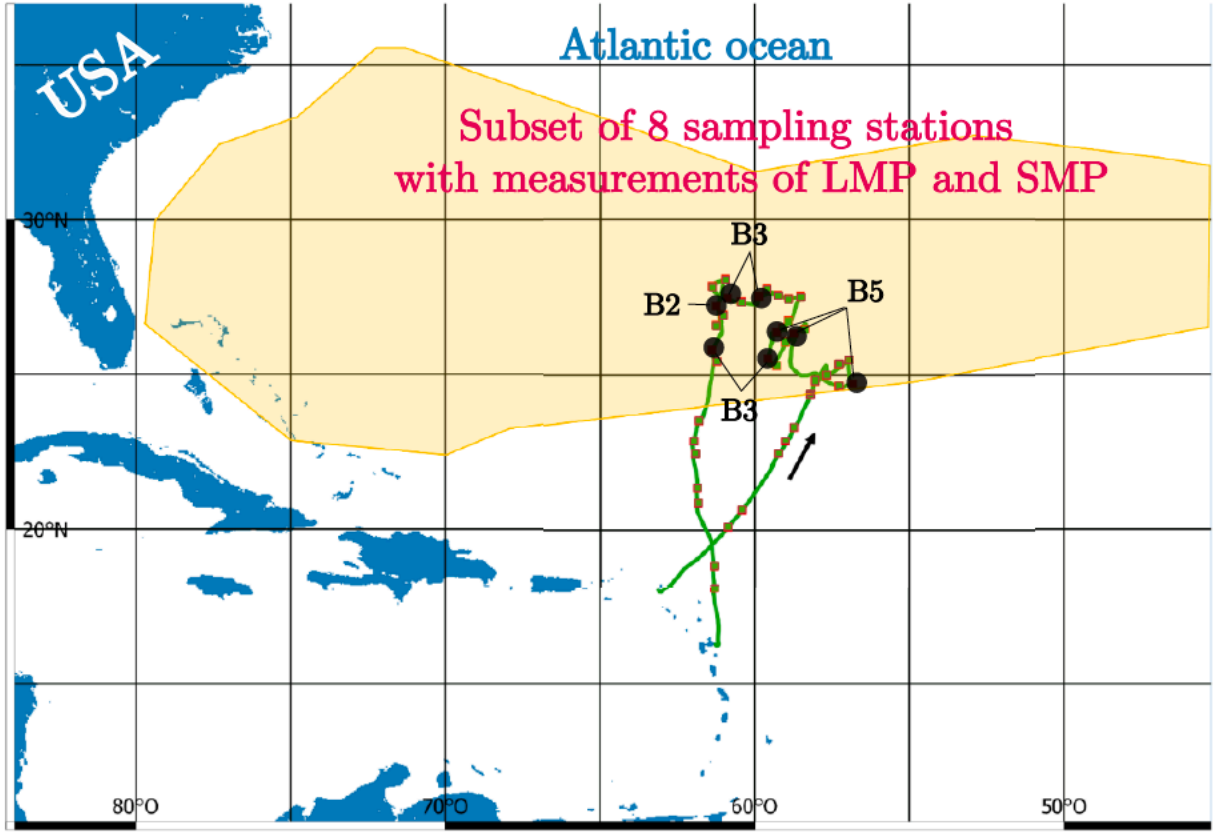


$$\frac{N_{cor}}{N_{tow}} = \frac{\text{Nb of plastic in water column}}{\text{Nb of plastic in Manta net}}$$

2.2. Implication for microplastics estimates (at sea)

LMP : large microplastics
(1mm < L < 5mm)
SMP: small microplastics
(25µm < L < 1mm)

- Applying our approach to sea campaign of **NGO expedition 7th Continent in the North-Atlantic gyre (2015)**

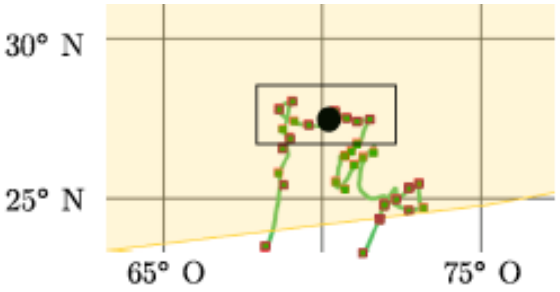


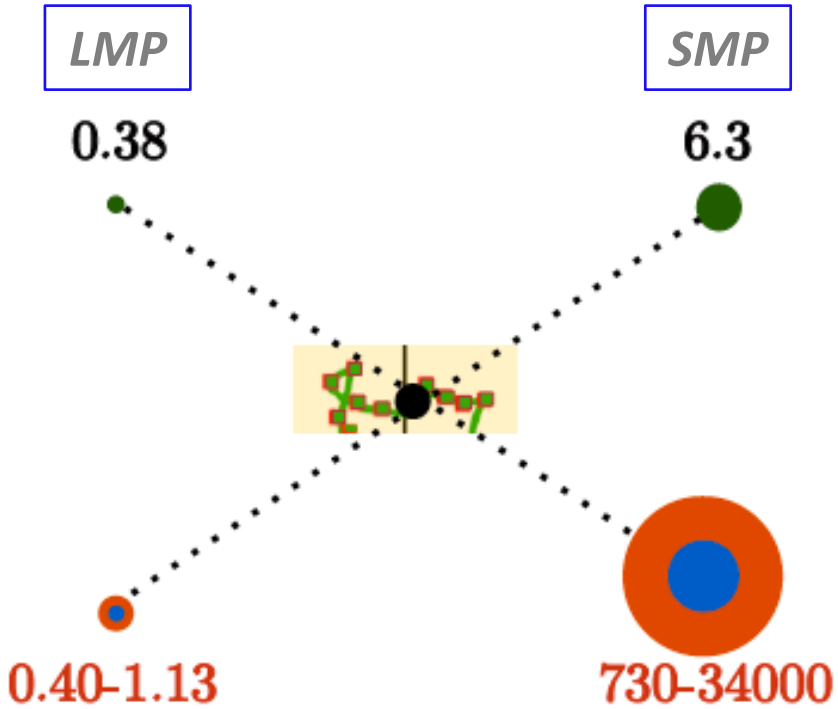
2.2. Implication for microplastics estimates (at sea)

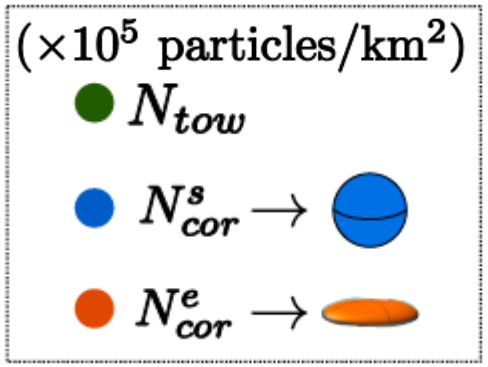
LMP : large microplastics
(1mm < L < 5mm)
SMP: small microplastics
(25µm < L < 1mm)

- Applying our approach to sea campaign of **NGO expedition 7th Continent in the North-Atlantic gyre (2015)**

For each station



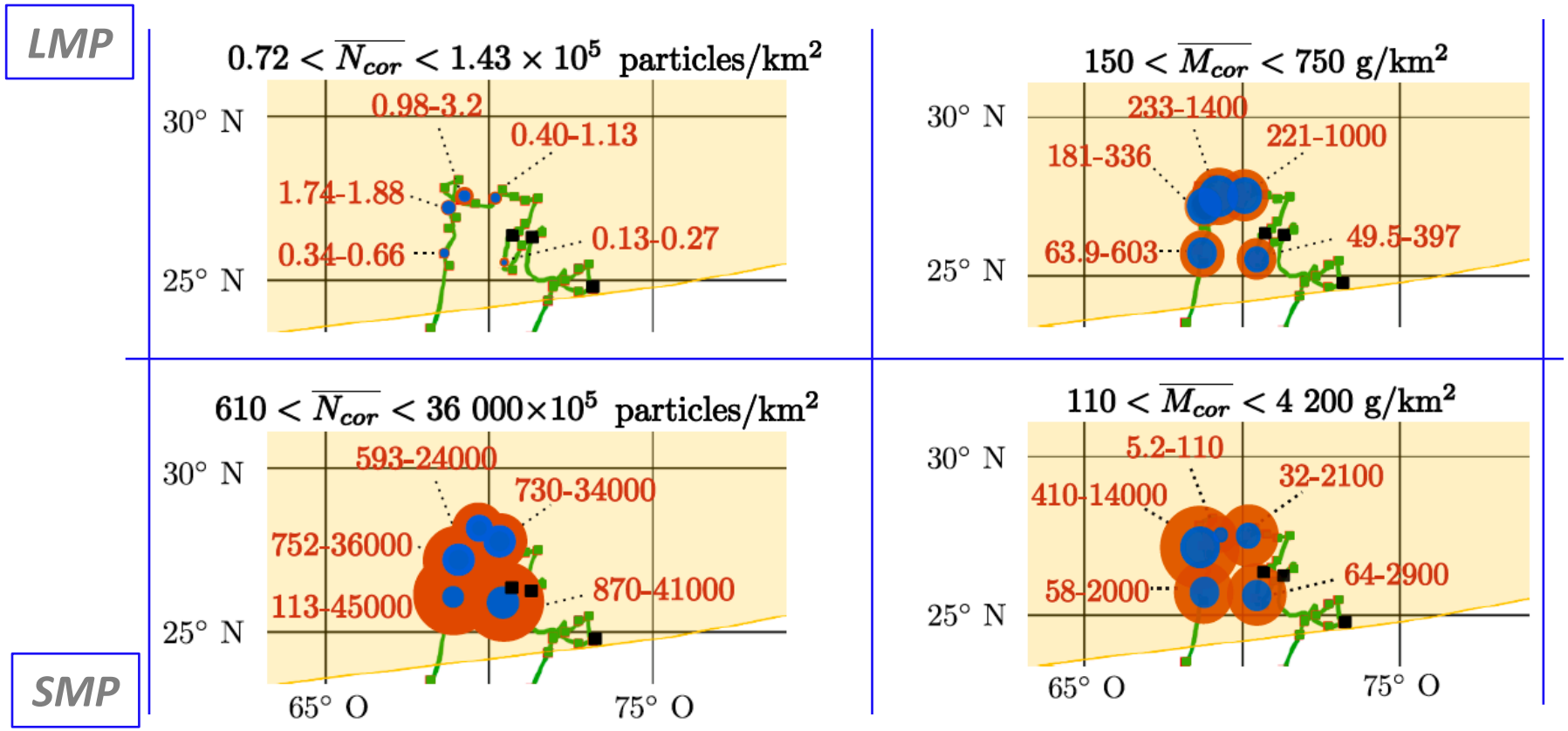




2.2. Implication for microplastics estimates (at sea)

LMP : large microplastics
(1mm < L < 5mm)
SMP: small microplastics
(25µm < L < 1mm)

- Applying our approach to sea campaign of **NGO expedition 7th Continent in the North-Atlantic gyre (2015)**

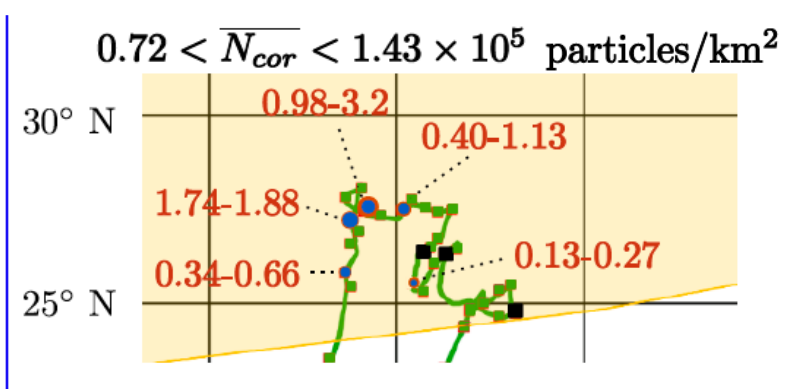


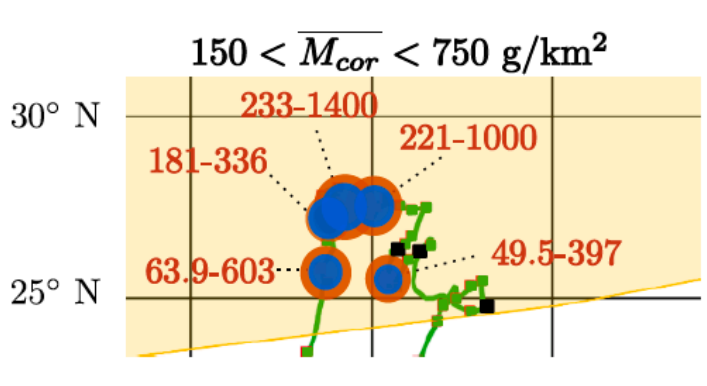
2.2. Implication for microplastics estimates (at sea)

LMP : large microplastics
(1mm < L < 5mm)
SMP: small microplastics
(25µm < L < 1mm)

- Applying our approach to sea campaign of **NGO expedition 7th Continent in the North-Atlantic gyre (2015)**

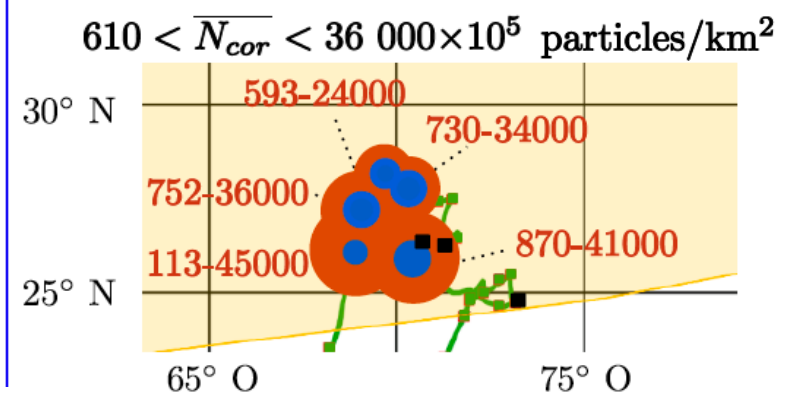
LMP

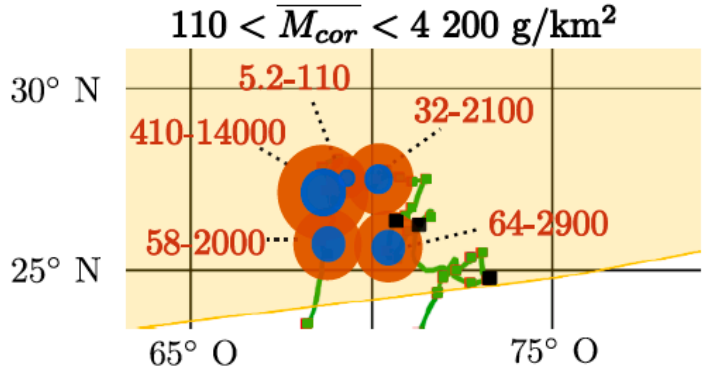




SMP are ~1000 more numerous than LMP

$$850 < \frac{SMP}{LMP} < 2\,520$$





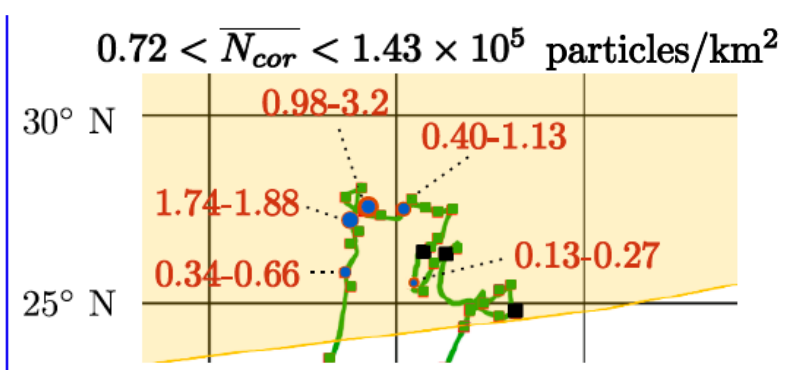
SMP

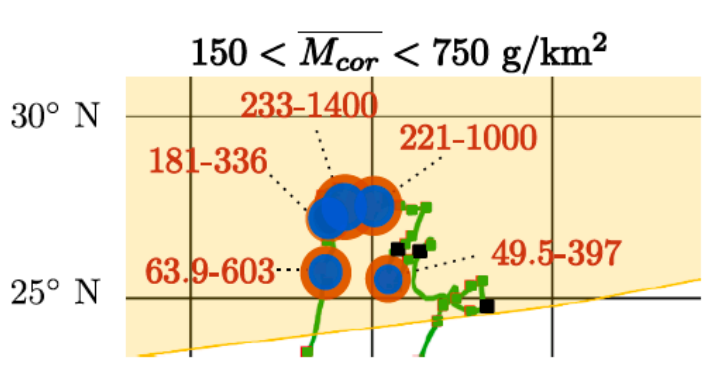
2.2. Implication for microplastics estimates (at sea)

LMP : large microplastics
(1mm < L < 5mm)
SMP: small microplastics
(25µm < L < 1mm)

- Applying our approach to sea campaign of **NGO expedition 7th Continent in the North-Atlantic gyre (2015)**

LMP



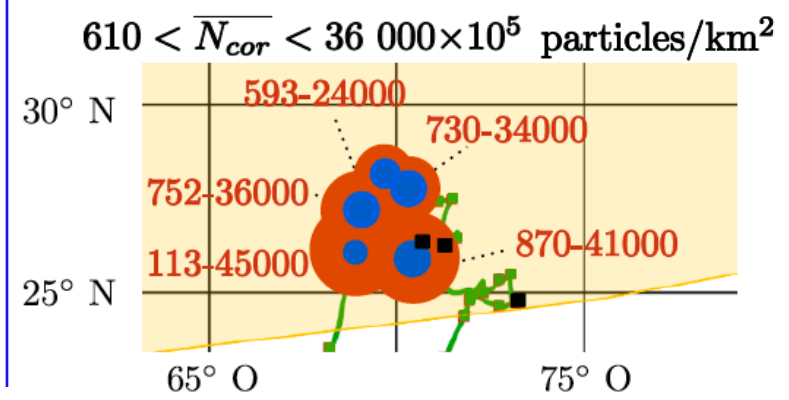


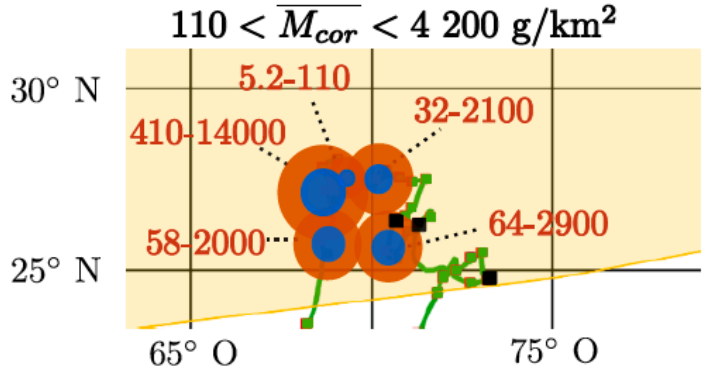
SMP are ~1000 more numerous than LMP

Mass of SMP is similar to that of LMP

$850 < \frac{SMP}{LMP} < 2\,520$

$0.73 < \frac{SMP}{LMP} < 5.6$





SMP

Conclusions

LMP : large microplastics (1mm < L < 5mm)

SMP: small microplastics (25µm < L < 1mm)

- Physically-based model provides plastic **concentration estimates in number and mass**

- Influence of surface mixing is very important for small microplastics (SMP), and they were not adequately modelled previously.

- Systematic measures for sea samples (**LMP + SMP**) have shown **range of concentrations very different for the two classes of size** → **mass of SMP = mass of LMP in North Atlantic Ocean (NAO)**

Poulain et al., Environ. Sci. Technol. 2019, 53, 3, 1157-1164 https://doi.org/10.1021/acs.est.8b05458

PLASTICOUNT= tool for sea-surface estimates available https://sourceforge.net/projects/plasticount/

Perspectives

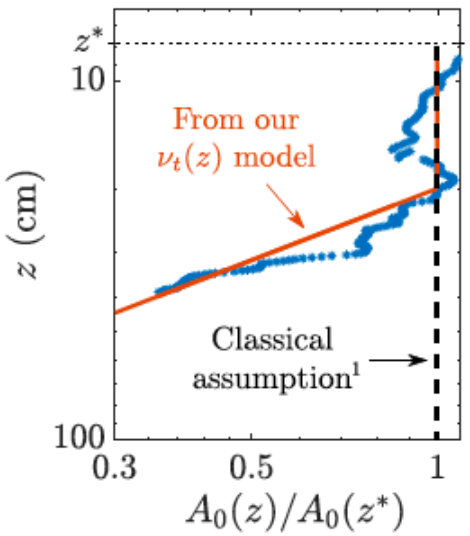
- **Turbulent mixing model**

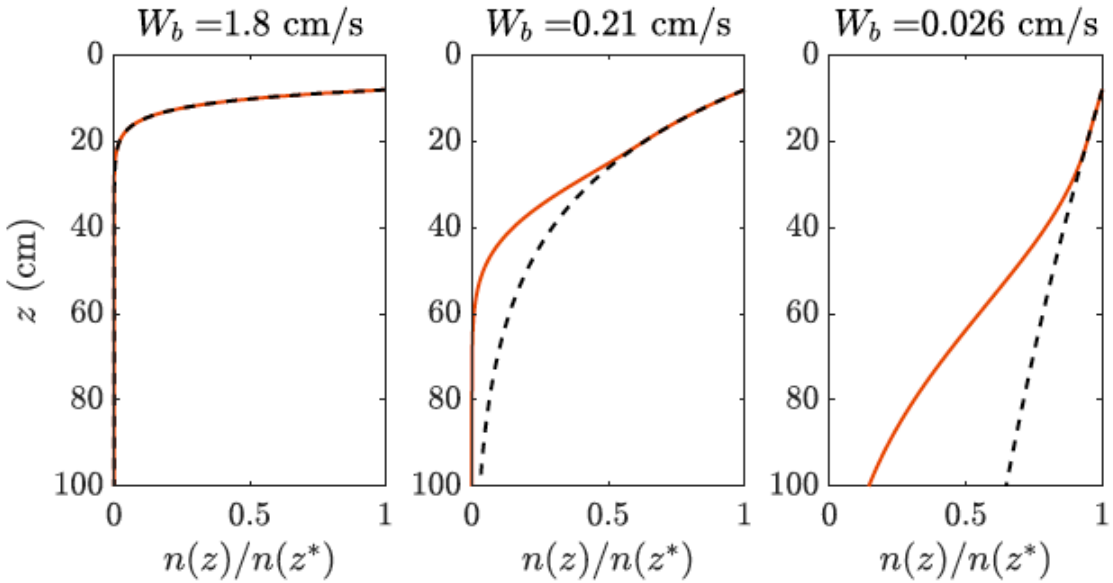
what shall be $A_0(z)$ like?

Impact on n(z) ?

Publication to come soon…

(Marie Poulain's PhD)





- Influence of the **surface sampling method** is important → **testing new protocols** at several depths (more than 1), size measurements important too! Ongoing analysis

Expedition 7th Continent 2019 in Mediterranean Sea (PI A. ter Halle, Y. Ourmières)

- Revisiting global estimates with our approach … ongoing work, it seems to confirm NAO results

EGU21-5026,
26/04/2021

Uncertainties on plastic concentration estimates at sea

Matthieu Mercier (IMFT, France), Marie Poulain-Zarcos (IMFT-IMRCP, France), Alexandra ter Halle (IMRCP, France), Florian Simatos (ISAE, France), Marion Saint-Martin (IMFT, France)

Motivations:

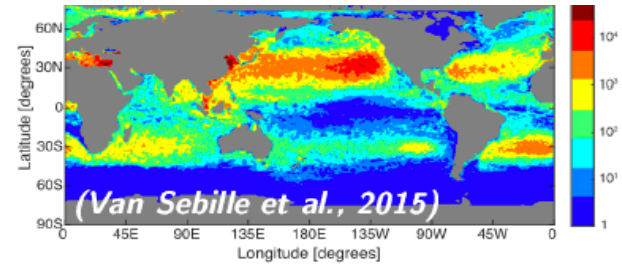
- It is commonly said that we find back only ~1% of plastic incoming at sea

  Where is the rest ?

- Field measurements play a very strong part in these estimates, with surface values and corrected concentrations for wind/wave mixing.

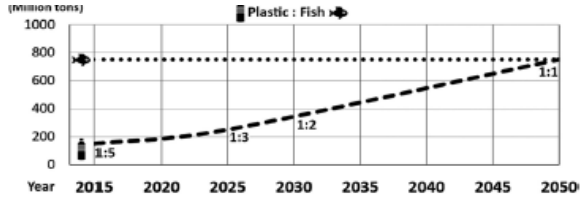
  Confidence in 'corrected' field measurements ? Error bounds ?

Between 0.093 and 0.236 Mtons in total



mismatch

~15 Mtons /year entering the oceans

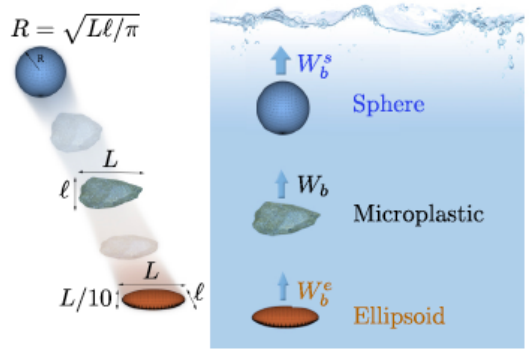


(Crawford & Quinn, 2017)

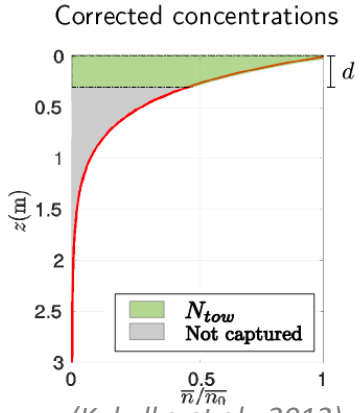
Our work:

- Using vertical mixing with physically-based model for plastic geometries to provide plastic **concentration estimates in number and mass** for **Large MicroPlastics and Small MicroPlastics.**

LMP : large microplastics (1mm < L < 5mm)
SMP: small microplastics (25µm < L < 1mm)

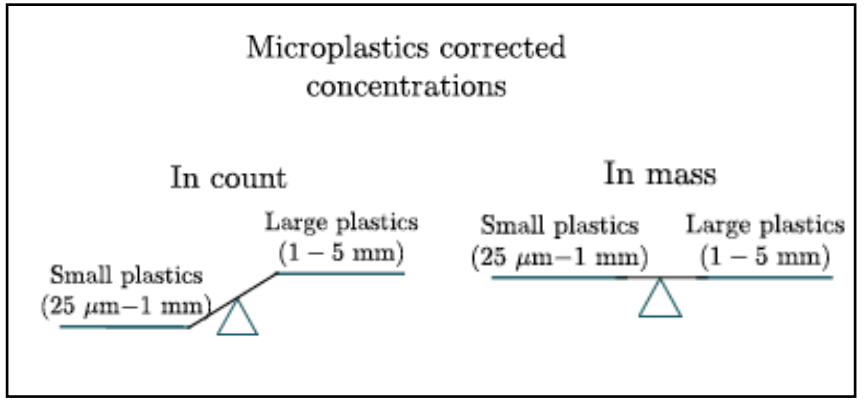


+



(Kukulka et al., 2012)

→



- Influence of **surface mixing is very important for SMP.** Systematic samplings of LMP + SMP have shown that **mass of SMP = mass of LMP in North Atlantic Ocean (NAO**