Plastics as Tracers to Understand Physical Ocean Processes

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WHOI Microplastics
18 October 2019

Motivating Questions

Plastics as a contaminant:

- Where is all the plastic? (Mass budget)
- What is the environmental fate of ocean plastics? (Transformation & sinks)
- *What are the biological impacts of ocean plastics?*

Plastics as a tracer:

- How can the distribution and transport of ocean plastics inform our understanding of ocean physics?

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Measuring surface plastic since the 1980s

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Plankton net particles: the tracer

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Particle size: mass, area, length

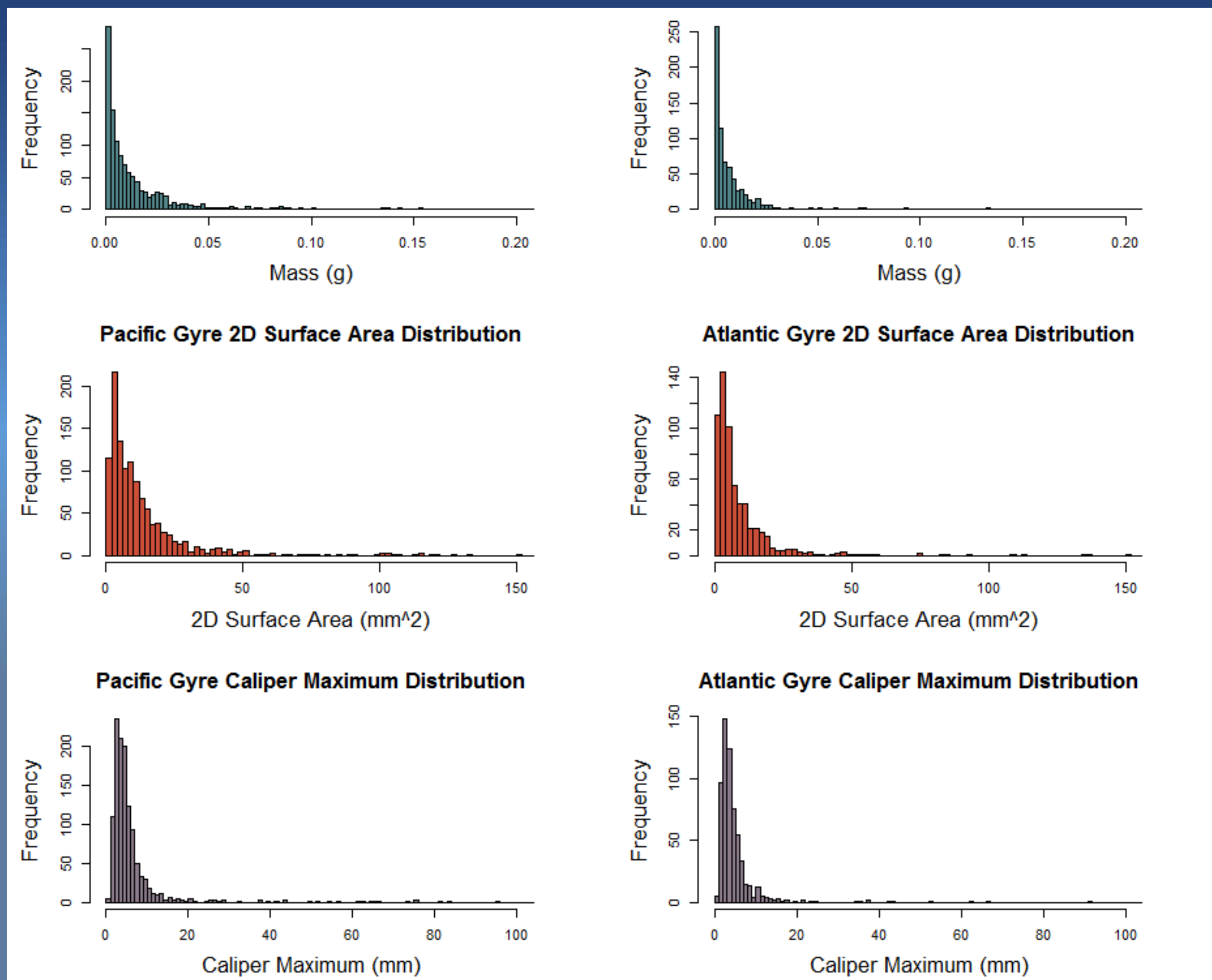
N. Pacific gyre > N. Atlantic gyre

North Pacific | North Atlantic

Mass

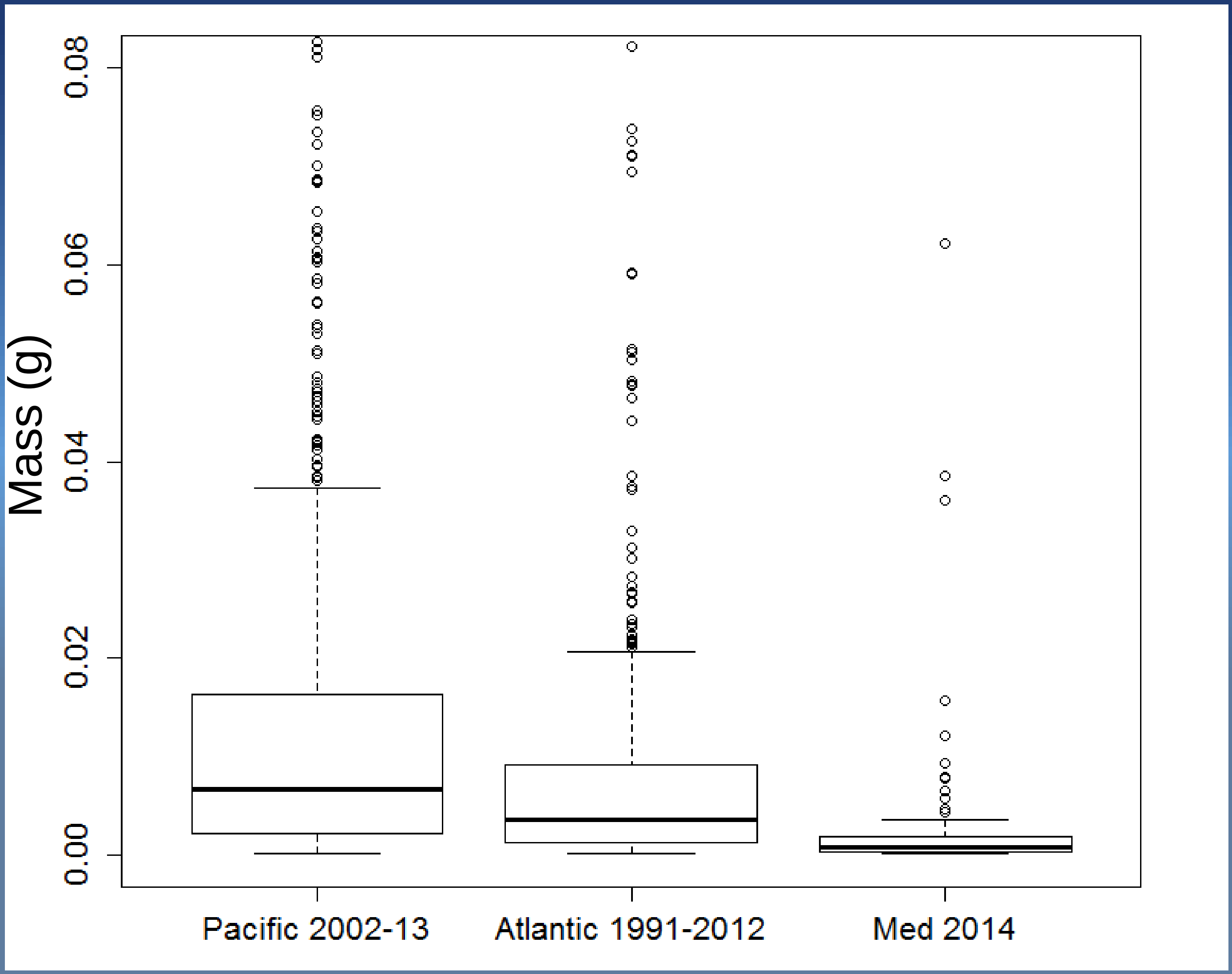
Surface Area

Length



Particle mass: fragments only

N. Pacific gyre > N. Atlantic gyre > Med.



North Atlantic polymer type

Polymer type	Count (#)	% by count	Mass (g)	% by mass	N.A. Prod.[1]	U.S. MSW[2]
PE	843	77.1	12.76	67.6	12.34	9.69
PP	61	5.6	0.62	3.3	5.70	2.89
PS	12	1.1	0.16	0.8		2.14
PE+PP	2	0.2	0.01	0.0		
Unknown	175	16.0	5.33	28.2		

[1] Average North American resin production in million metric tons from 1986-2007 (ACC)
[2] Average municipal solid waste generation in million metric tons from 1993-2007 (U.S. EPA)

20:1

~2:1

~3:1

SEA data: western North Atlantic

> 6,600 plankton net tows from 1986 – 2010

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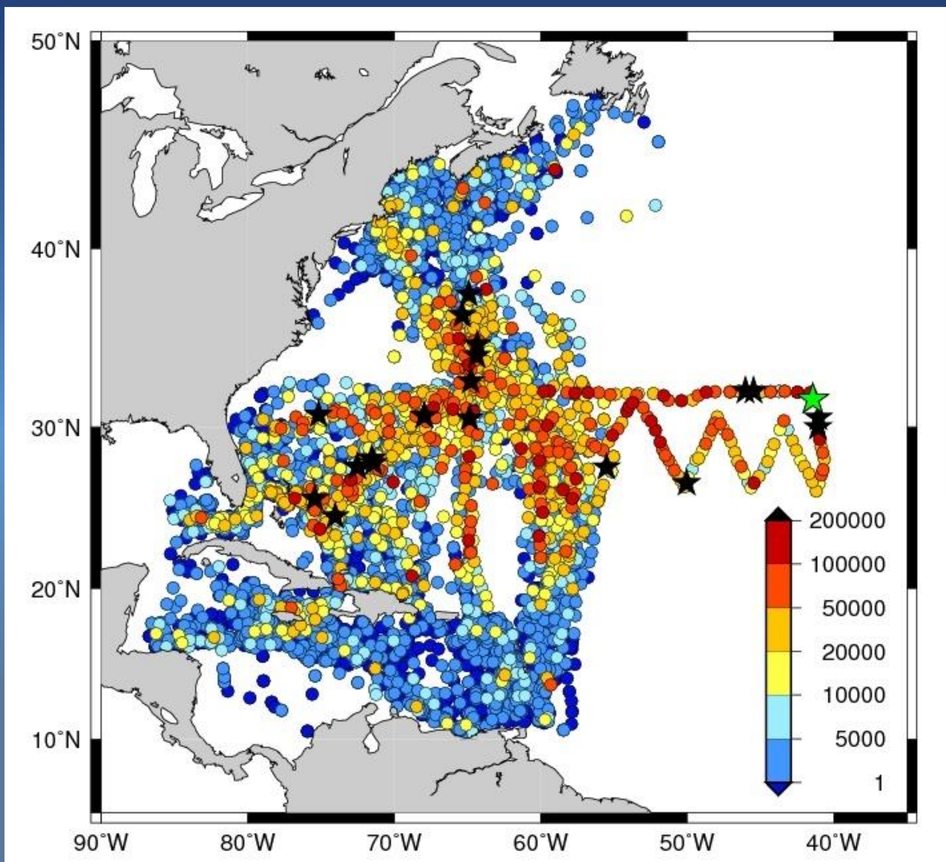

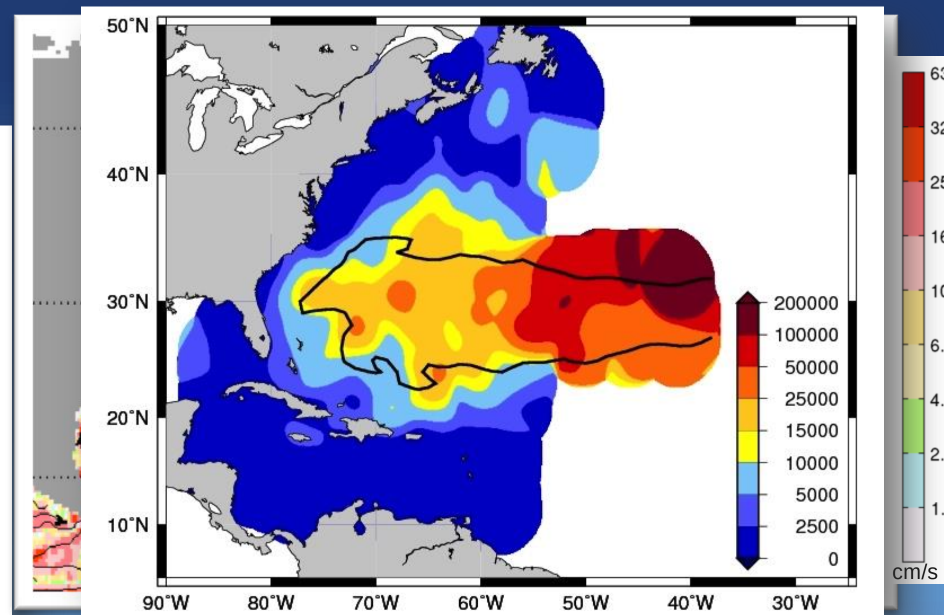

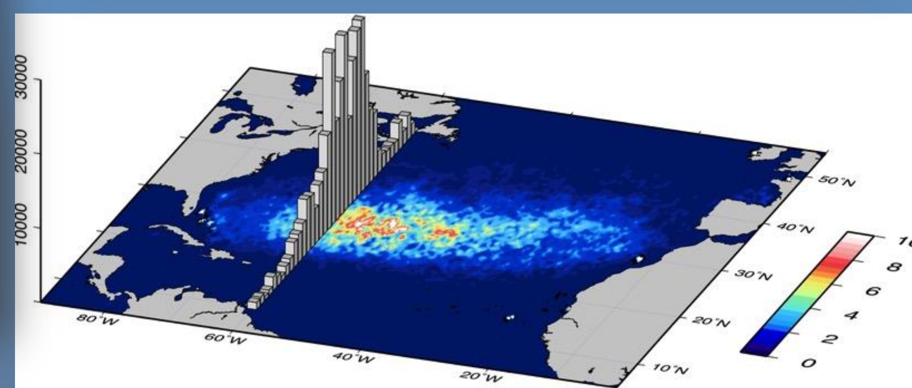

Law *et al.*, 2010

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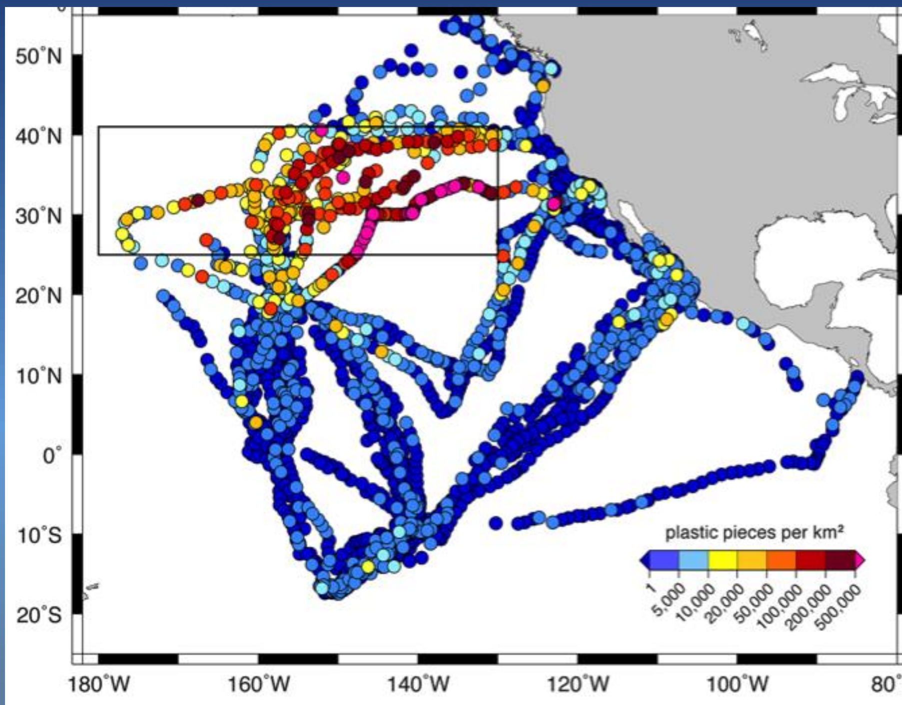
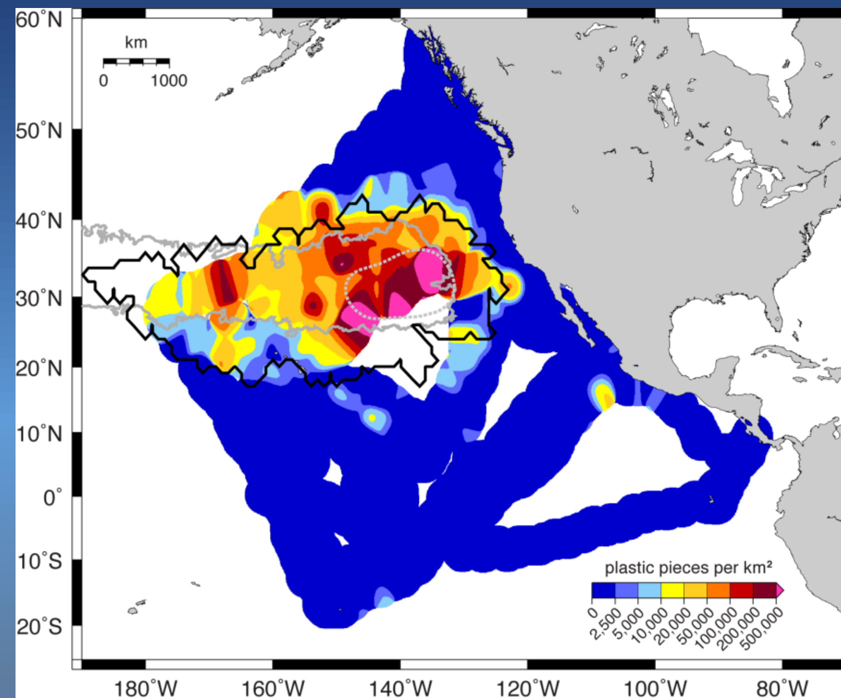
SEA data: eastern Pacific Ocean

> 2,500 plankton net tows from 2001-2012

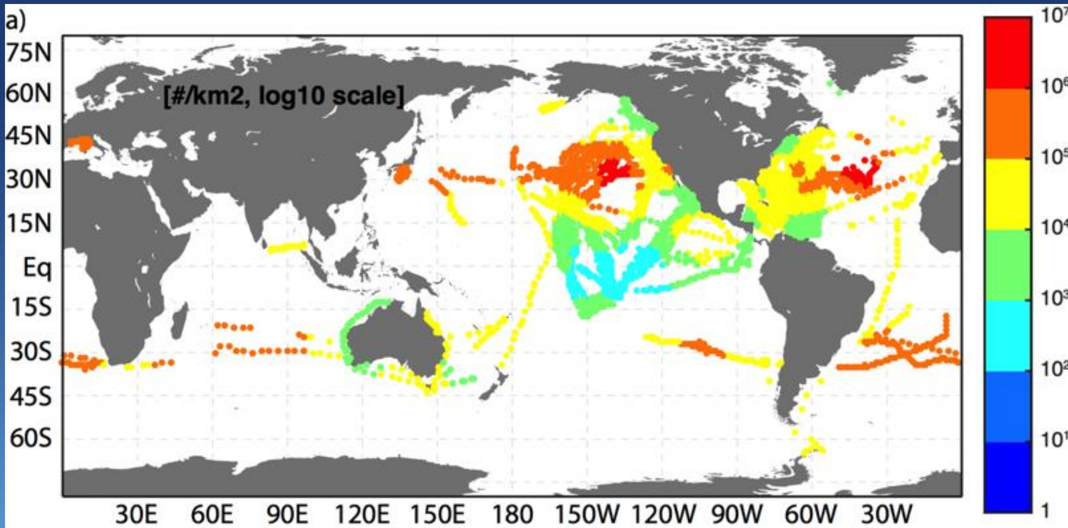


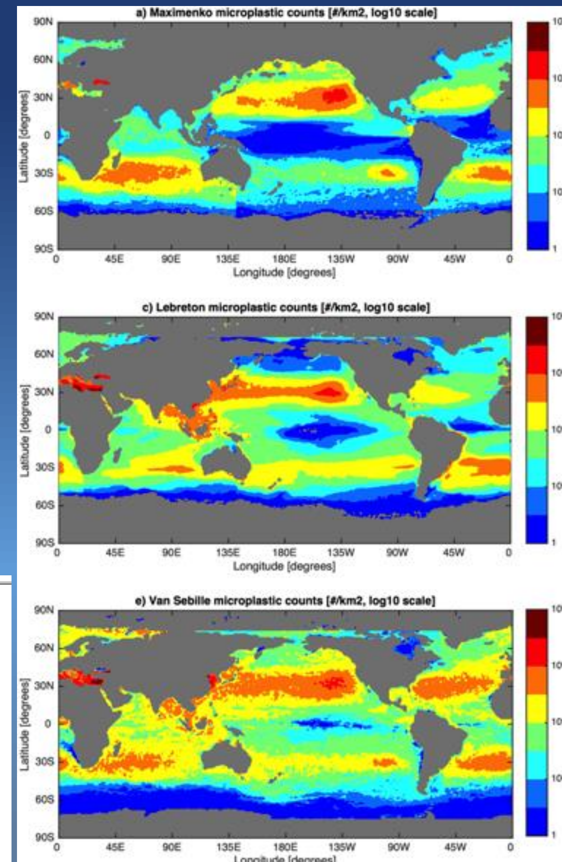


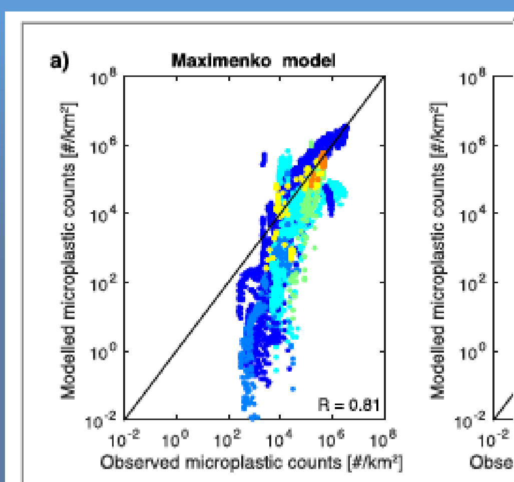
Law *et al.*, 2014

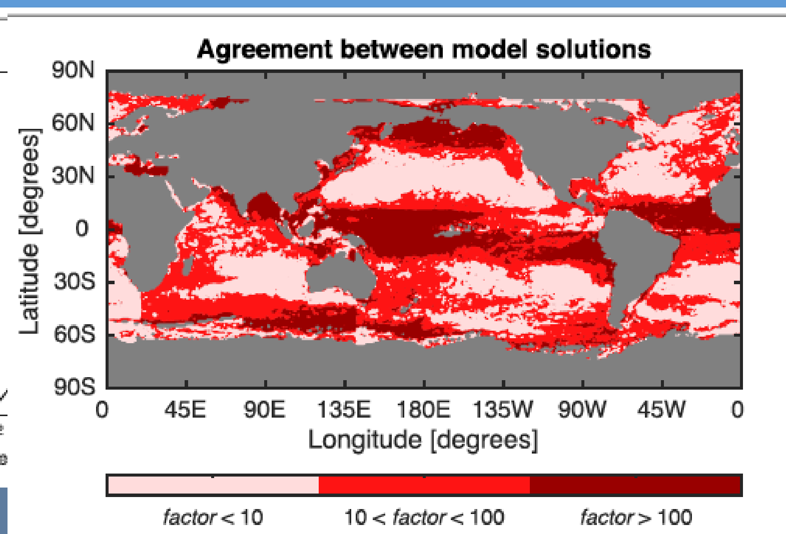
Global plankton net tows

> 11,800 tows between 1971 – 2013



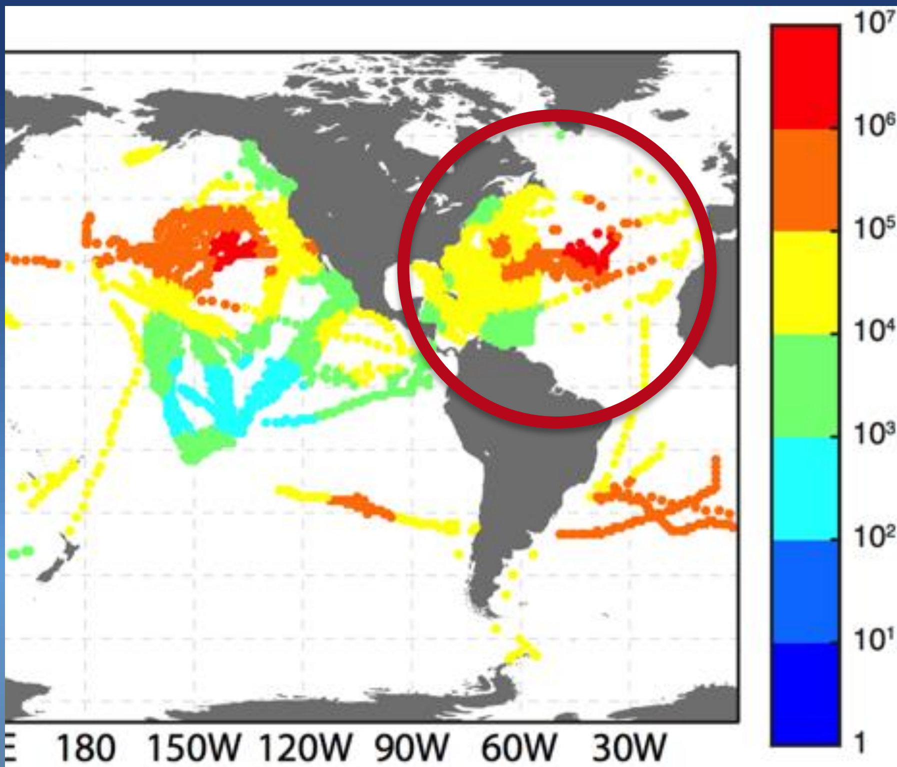


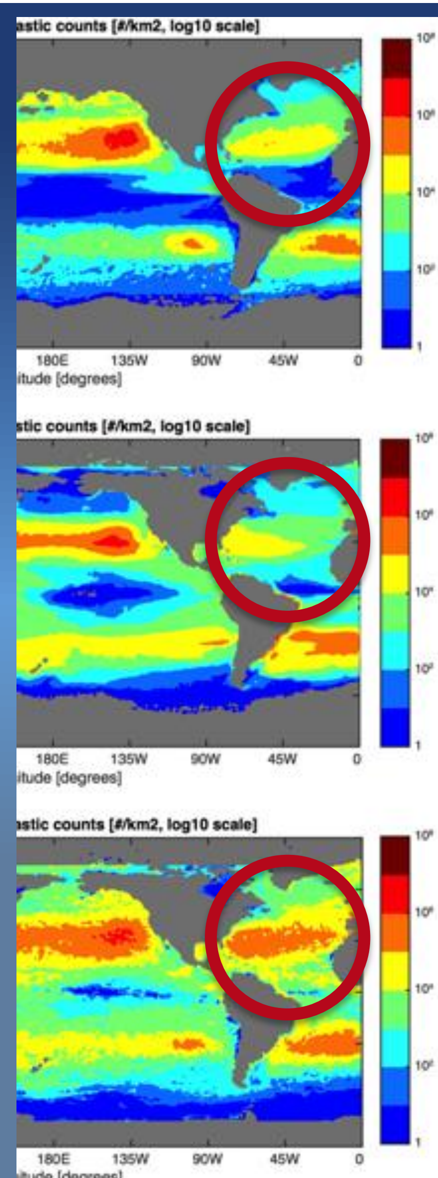




Van Sebille *et al.*, 2015

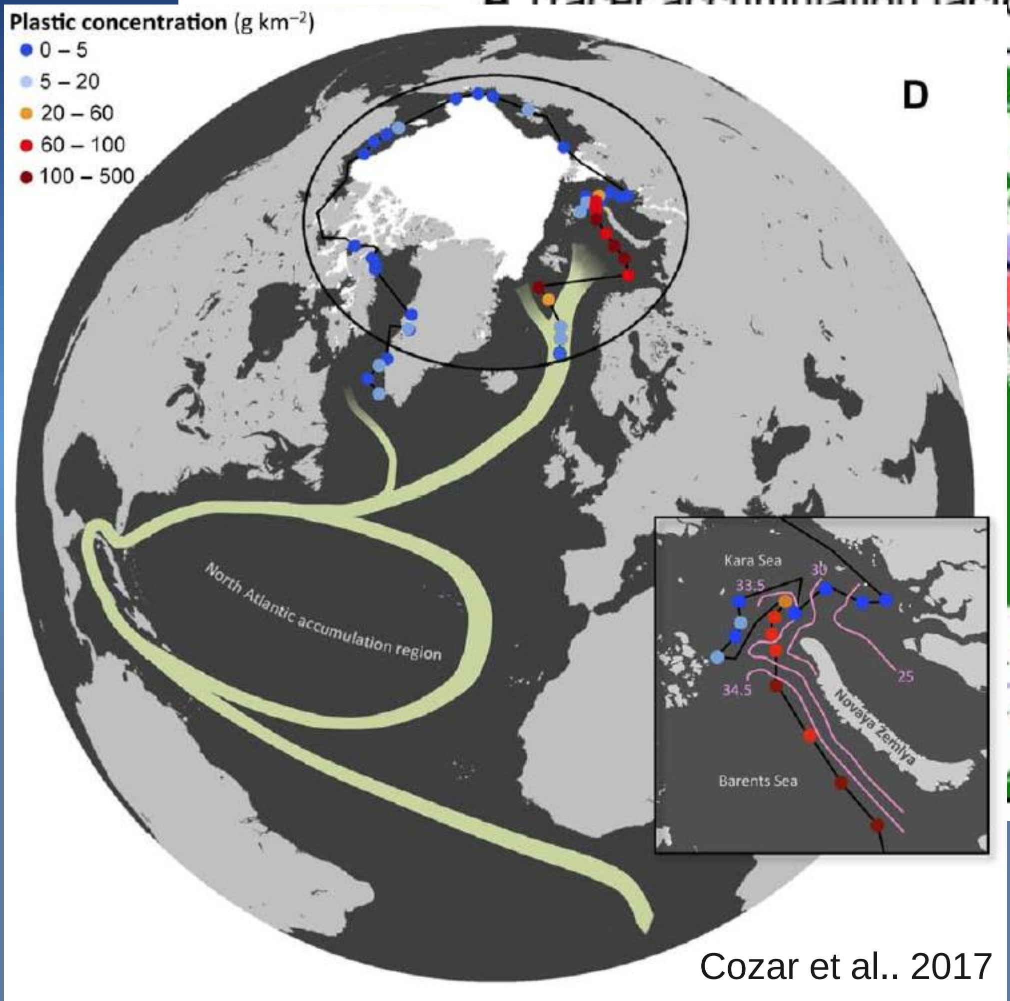
Data informing models
North Atlantic



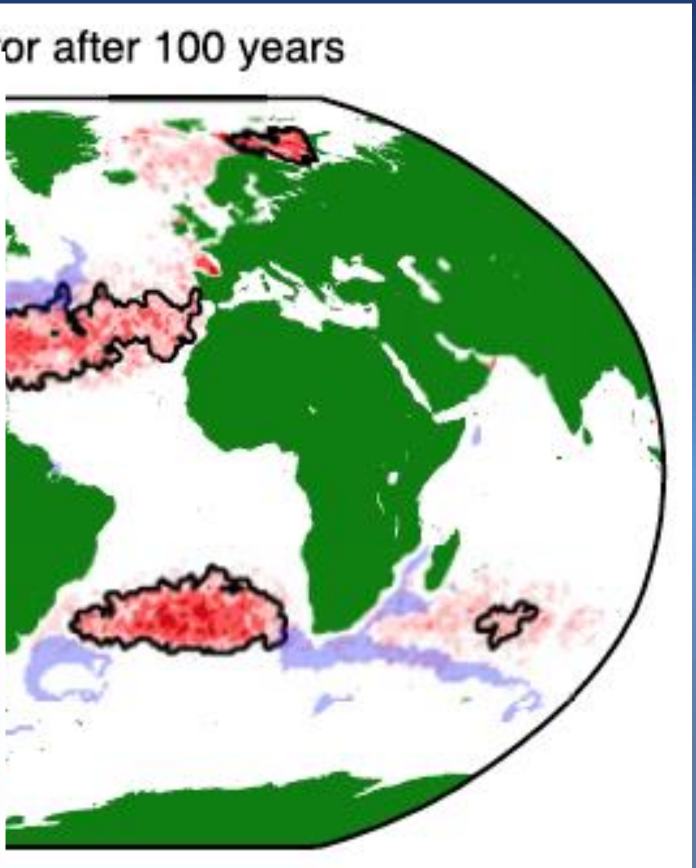


Van Sebille *et al.*, 2015

Models informing data:
Is there a 6th Garbage Patch?



Cozar et al.. 2017



Van Sebille *et al.*, 2012

Spatial and temporal variability:
Wind-driven vertical mixing

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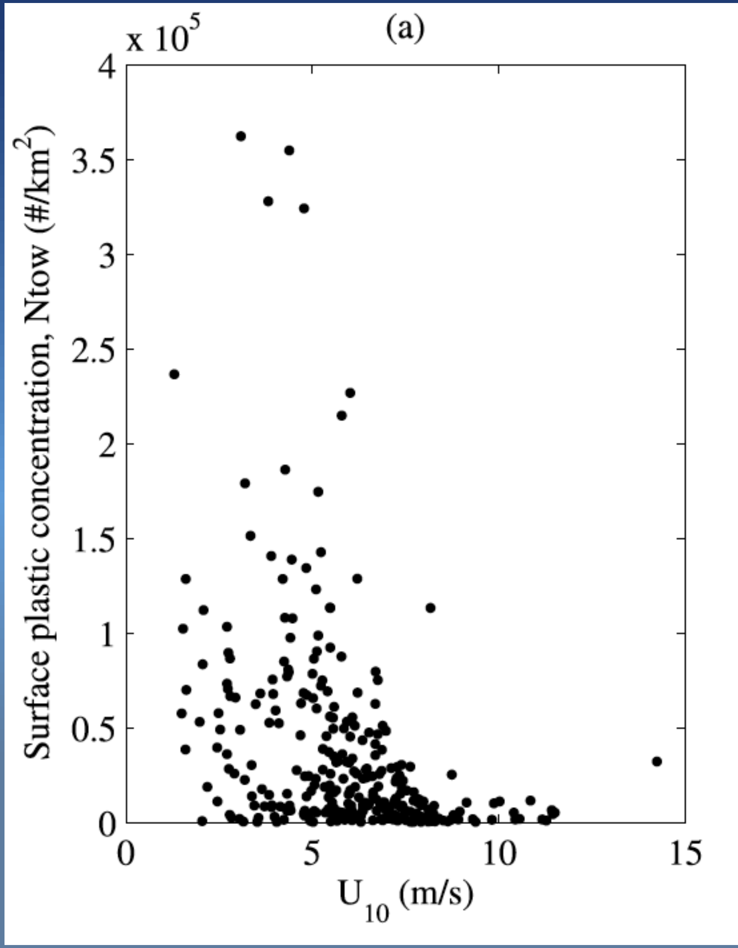

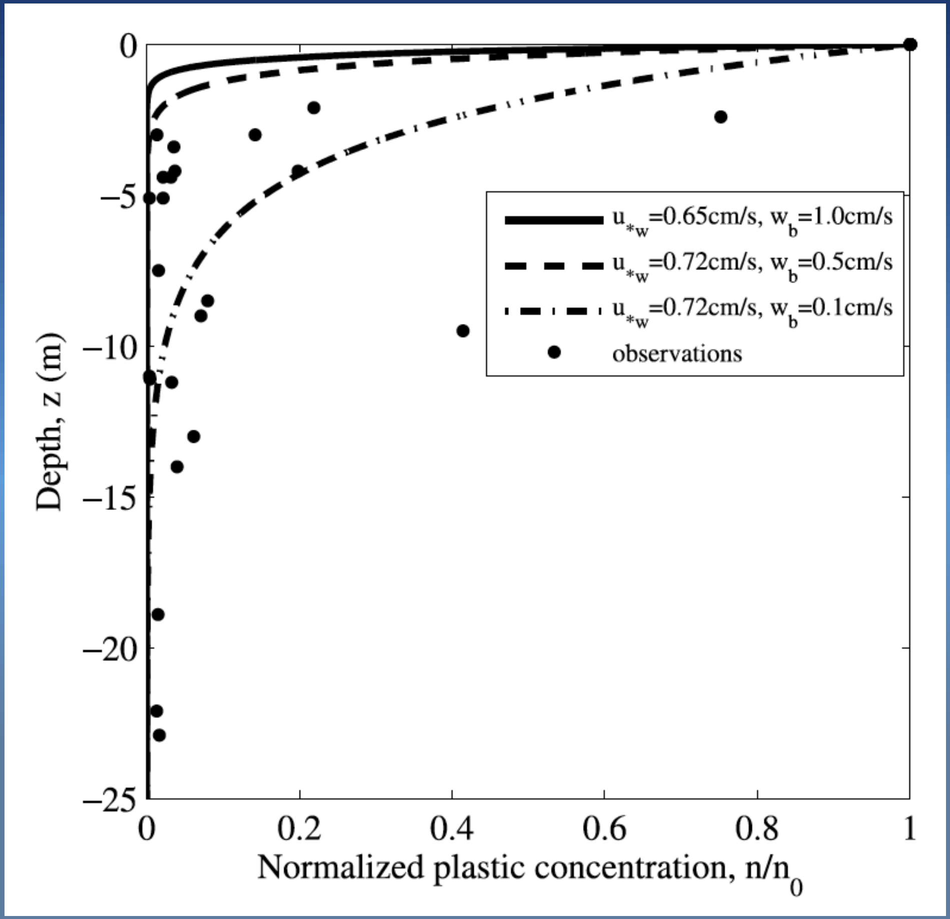

Kukulka *et al.*, 2012

Spatial and temporal variability:
Turbulent vertical mixing

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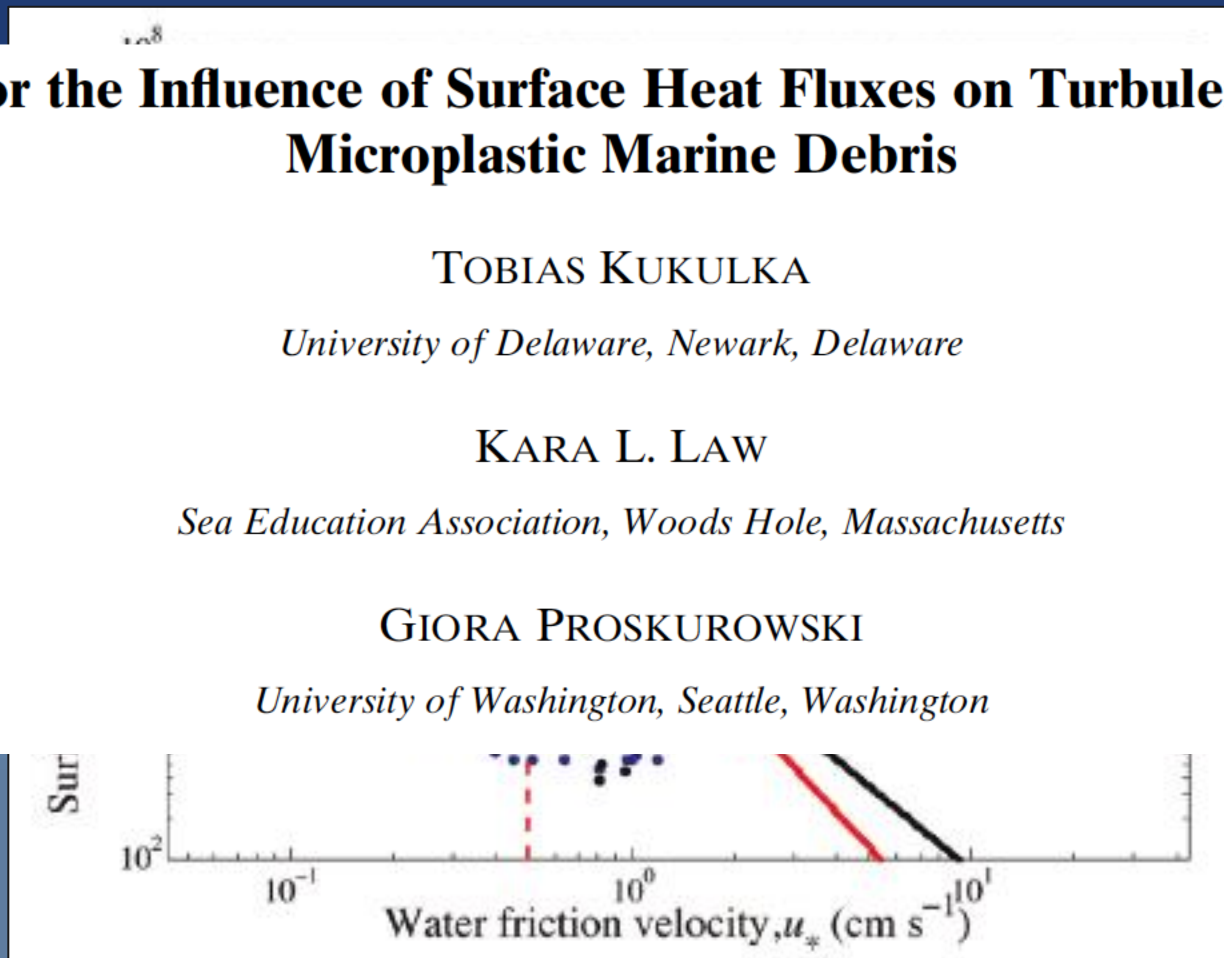

Evidence for the Influence of Surface Heat Fluxes on Turbulent Mixing of Microplastic Marine Debris

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Brunner *et al.*, 2015

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Spatial and temporal variability:
When is a windrow not a windrow?

SCOR Working Group 153:
Floating Litter and its Oceanic TranSport Analysis and Modelling (FLOTSAM)

Preamble

In September 2017, the Scientific Committee on Oceanic Research, with financial assistance of the National Science Foundation, approved and created the Working Group #153 on Floating Litter and its Oceanic TranSport Analysis and Modelling (FLOTSAM)

Members

Chairs and Vice-Chairs

1. Stefano Aliani (IT)
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3. Kara Lavender Law (US)
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2. Georg Hanke (EU-JRC)
3. Nancy Wallace (NOAA)

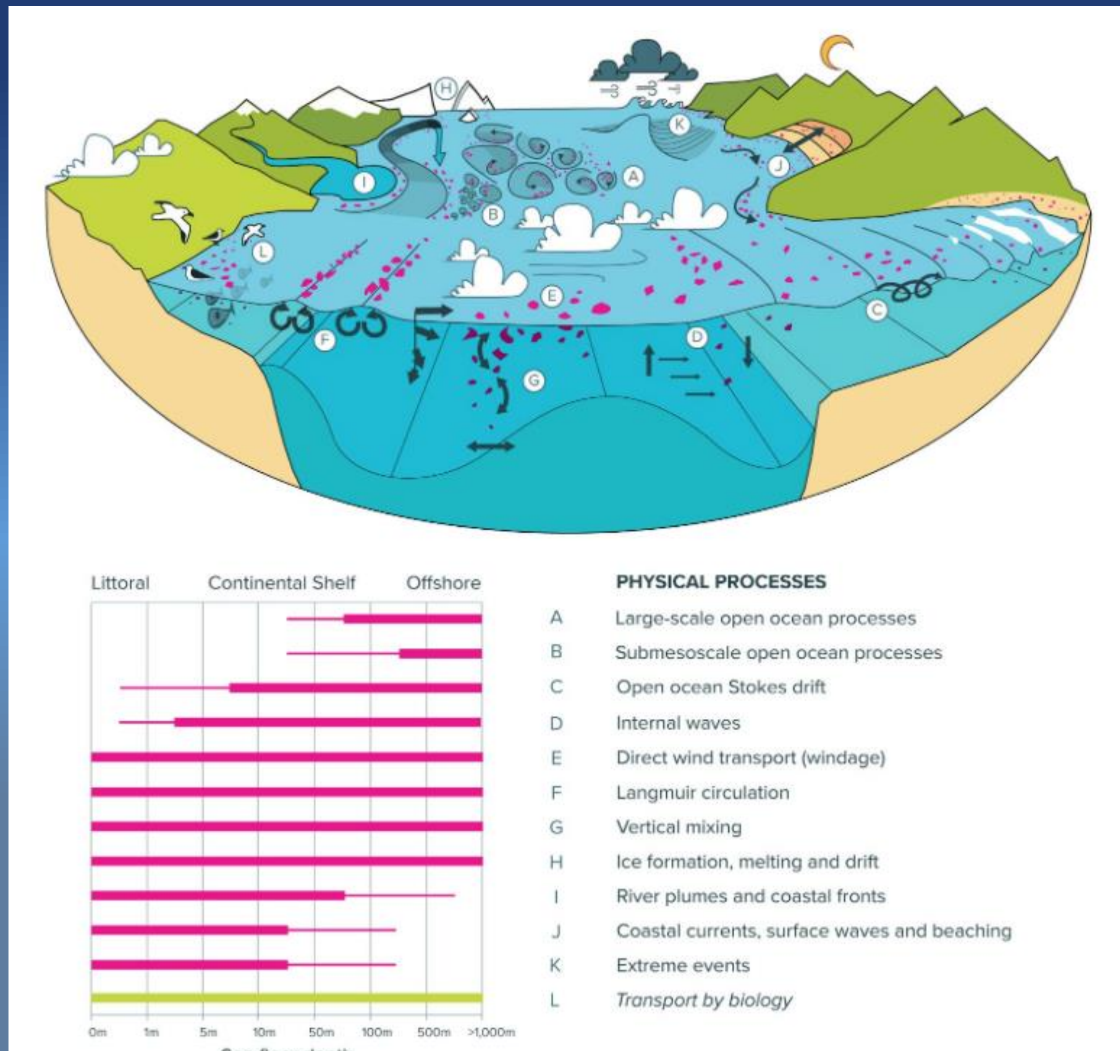
Review of physical processes

The physical oceanography of the transport of floating marine debris

Erik van Sebille[1], Stefano Aliani[2], Kara Lavender Law[3], Nikolai Maximenko[4], José M. Alsina[5], Andrei Bagaev[6,7], Melanie Bergmann[8], Bertrand Chapron[9], Irina Chubarenko[6], Andrés Cózar[10], Philippe Delandmeter[1], Matthias Egger[11], Baylor Fox-Kemper[12], Shungudzemwoyo P. Garaba[11,14], Lonneke Goddijn-Murphy[15], Britta Denise Hardesty[16], Matthew J. Hoffman[17], Atsuhiko Isobe[18], Cleo E. Jongedijk[19], Mikael L. A. Kaandorp[1], Liliya Khatmullina[6], Albert A. Koelmans[20], Tobias Kukulka[21], Charlotte Laufkötter[22], Laurent Lebreton[11], Delphine Lobelle[1,23,24], Christophe Maes[9,25], Victor Martinez-Vicente[26], Miguel Angel Morales Maqueda[27], Marie Poulain-Zarcos[28], Ernesto Rodríguez[29], Peter G. Ryan[30], Alan L. Shanks[31], Won Joon Shim[32], Giuseppe Suaria[2], Martin Thiel[33,34,35], Ton S. van den Bremer[36], and David Wichmann[1]

van Sebille et al., 2019, submitted

Physical ocean processes



van Sebille et al., 2019, submitted

Coastal ocean processes: A critical knowledge gap

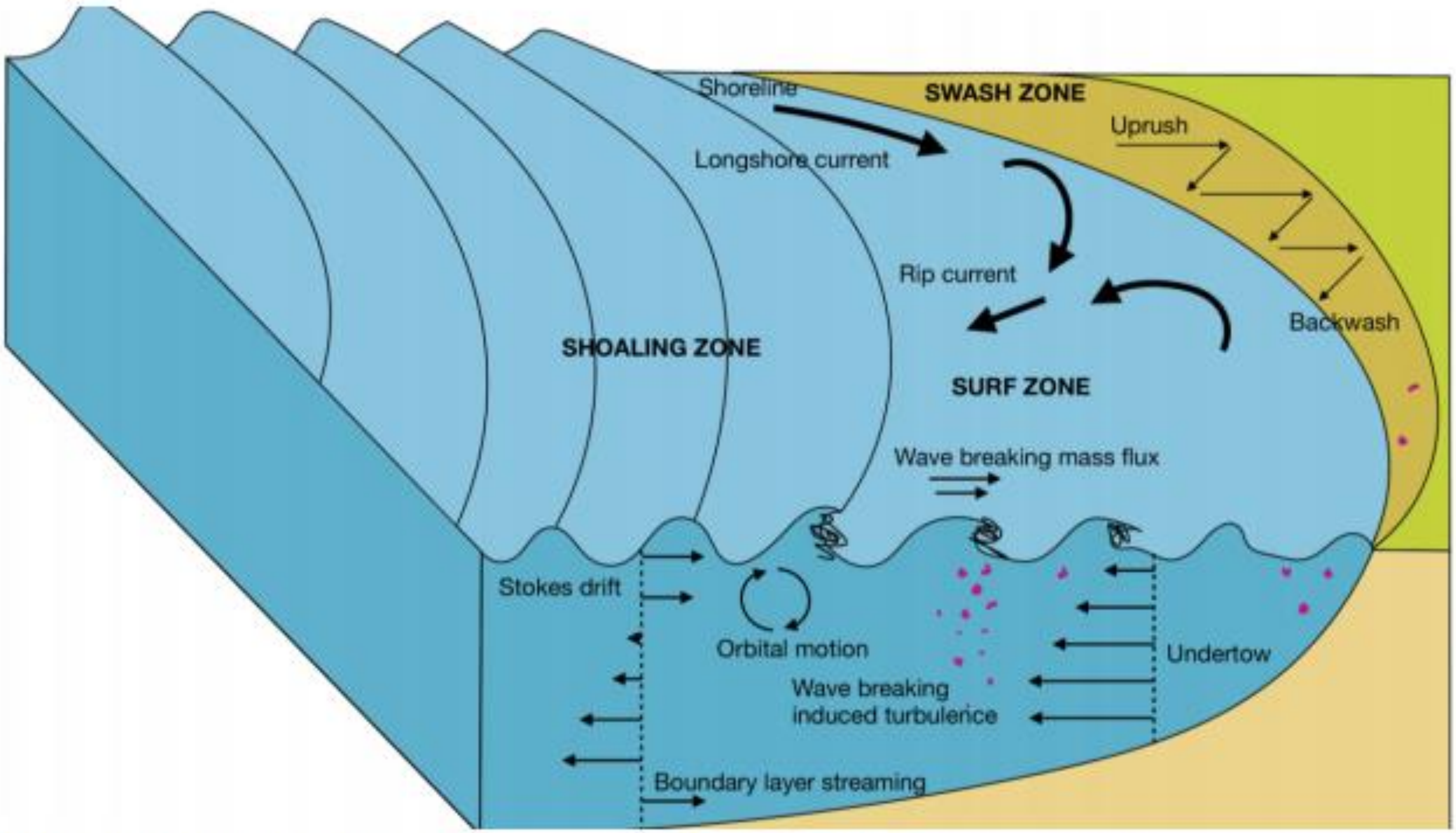
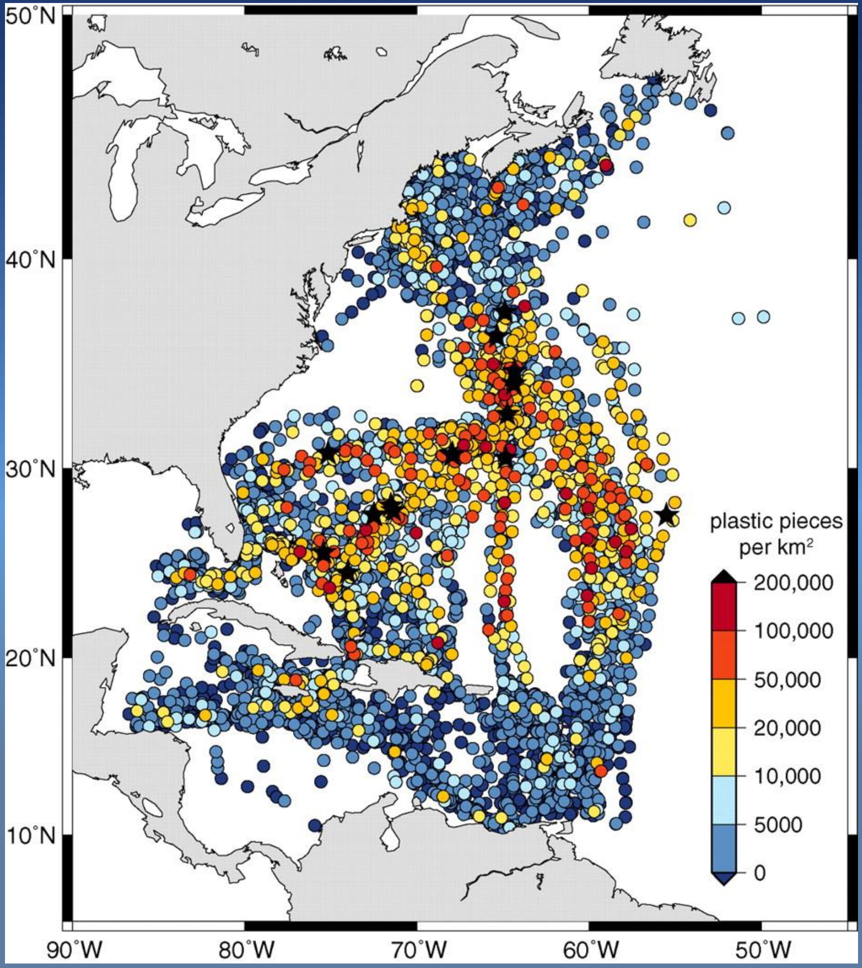
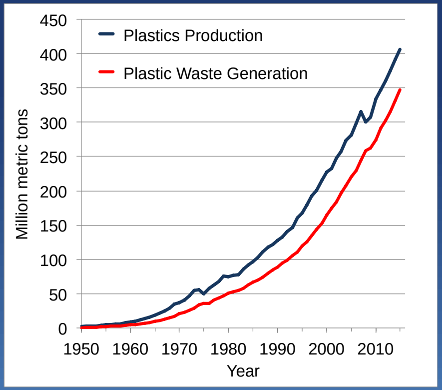


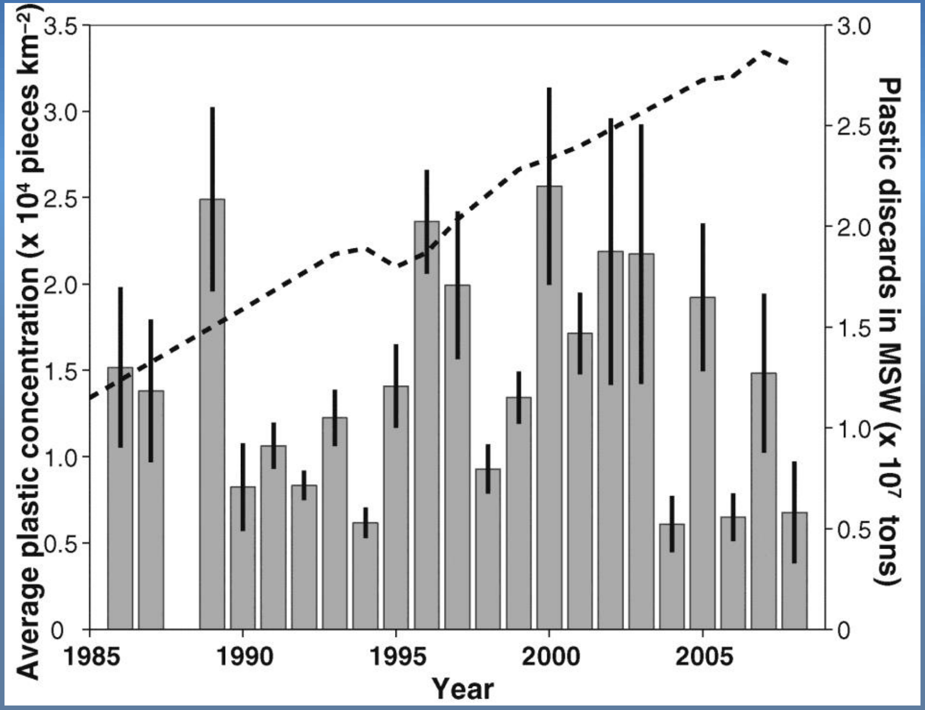
Figure 5: Schematic of the processes that transport plastics in the coastal zone. Adapted from Figure 1.2 of van der Zanden (2016).

van Sebille et al., 2019, submitted

Where is all the plastic?
No detectable trend 1986 – 2008







Law *et al.*, 2010

Lack of Observed Time Trend Hypothesis #1

<u>"Removal" processes:</u>

1. Transport to depth via:
   - Buoyancy increase (biological colonization)
   - Incorporation into sinking biological aggregates
   - Ingestion (vertically migrating species)
2. Coastal deposition
3. Fragmentation to sizes smaller than plankton net mesh (335 µm)

Collective removal rate > Input rate ??

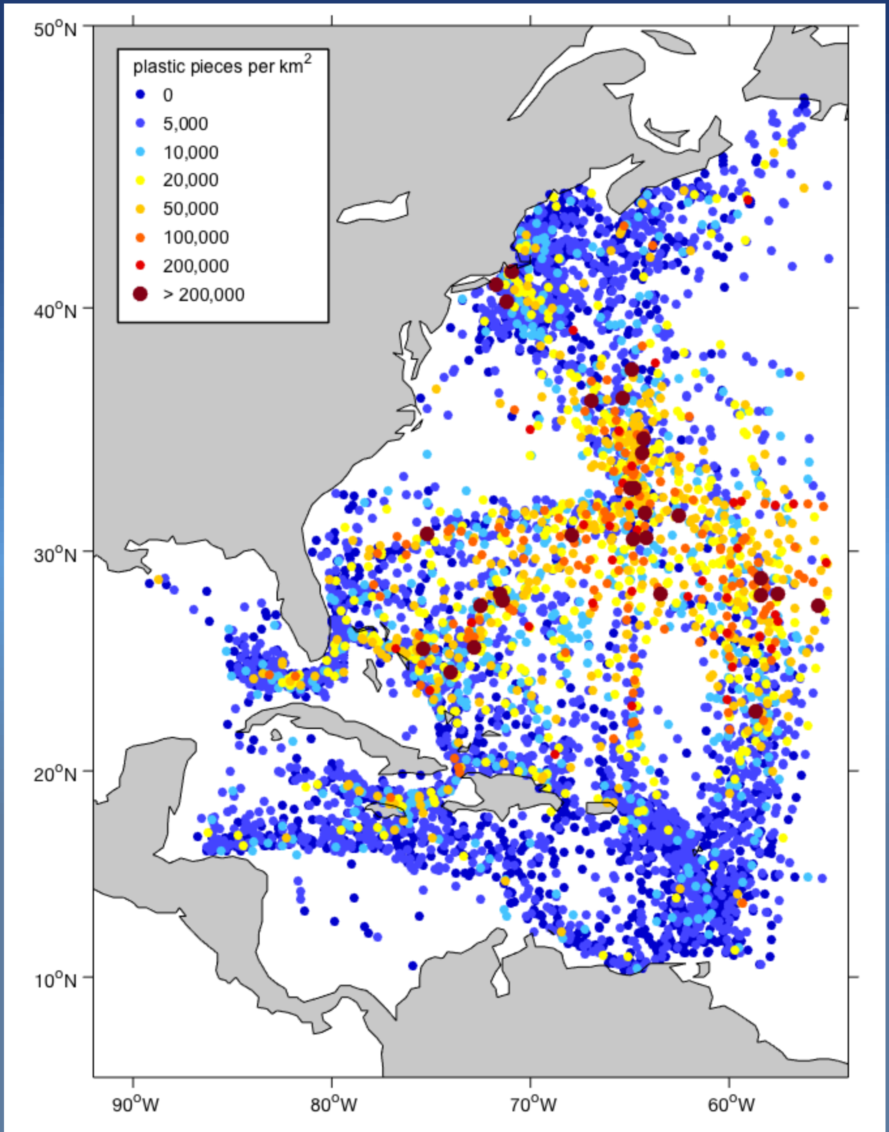
Lack of Observed Time Trend Hypothesis #2

Trend obscured by spatiotemporal variability in data set caused by:

1. Sampling conditions (e.g., tow length)
2. Wind-driven vertical mixing
3. Submesoscale surface convergences (D’Asaro et al. 2018; Laxaque et al. 2018)
4. Shifts in large-scale subtropical gyre
5. Variability in sampling locations over time

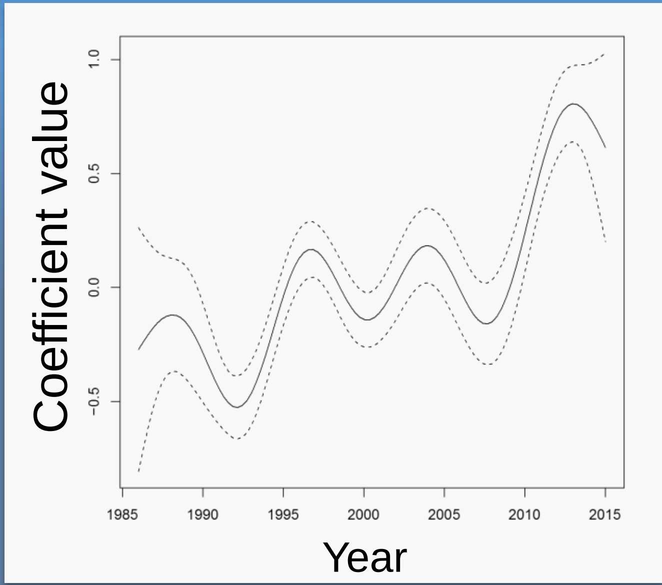
Generalized Additive Model

7,500 tows, 1986 – 2015



Evidence of a trend of microplastics concentration increasing *faster* than cumulative global plastic production.

Removal rate < Input rate!!



Wilcox *et al.*, in revision

Conclusions

1. Ocean physics influences plastics distribution
2. Ocean plastics are useful as a tracer
3. Neuston net data are useful…
4. ...even if they can't measure everything
5. ...and especially if you have amazing SEA Semester students!

OCEAN SCIENCES MEETING
16–21 FEBRUARY 2020
SAN DIEGO, CA, USA

PS008:
Physical processes governing the distribution and transport of dispersed particles in the ocean