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Fate of river-derived microplastics from the South China Sea

Yusuke UCHIYAMA
(Kobe Univ., Japan)

with Matsushita, K., Takaura, N. and Kosako, T.

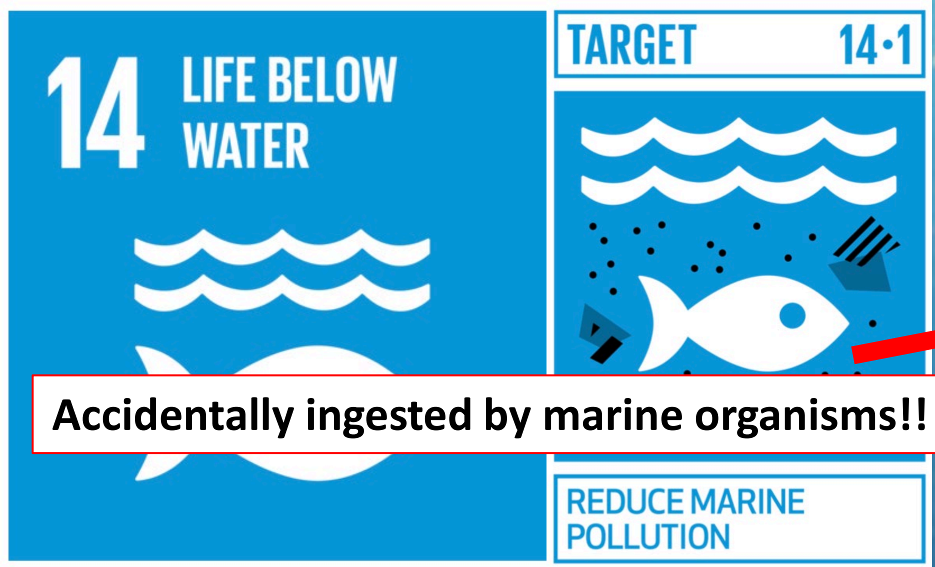
[Reference] Matsushita, K., Uchiyama, Y., Takaura, N. and Kosako, T. (2022): Fate of river-derived microplastics from the South China Sea: Sources to surrounding seas, shores, and abysses, *Environ. Pollut.*, Vol. 308, 119631.

Contents

Introduction

- *Marine Plastic Pollution* is one of the most important global environmental issues.
- Plastic fragments degraded into **a diameter of 5 mm or less** are called **"microplastics"** and found virtually everywhere in the global ocean.
- **Microplastics (MPs) may have a significant impact on our ecosystems.**

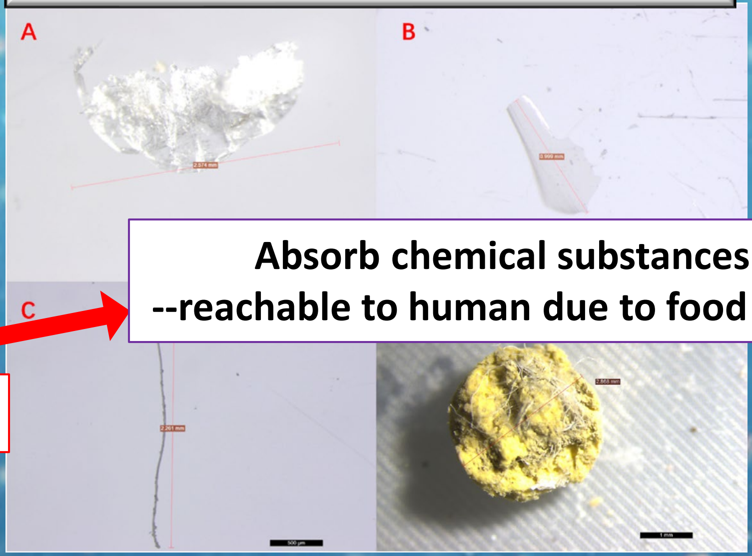
SDGs



Accidentally ingested by marine organisms!!

Microplastics

the size of 1mm or less is the most frequently



Absorb chemical substances --reachable to human due to food chain

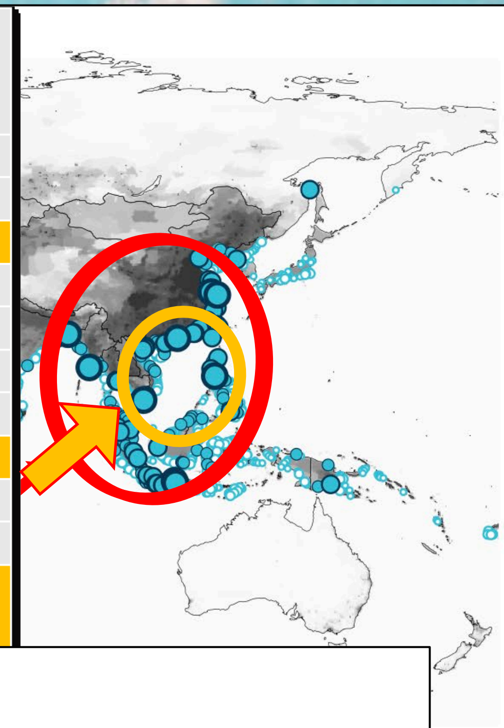
The three-dimensional distribution of MPs have not been fully studied yet.

✓ **Detailed numerical modeling studies are greatly demanded.**

Introduction

River-derived plastic waste input flux to the ocean

	Rivers	Country	Mass input estimate (tons・year^{-1})
1	Yangtze	China	333,000
2	Ganges	India	115,000
3	Pearl	China	106,000
4	Huangpu	China	41,000
5	Cross	Nigeria, Cameroon	40,000
6	Brantas	Indonesia	39,000
7	Amazon	Brazil, Peru,Columbia,Ecuador	39,000
8	Pasig	Filippines	39,000
9	Irrawaddy	Myanmar	35,000
10	Solo	Indonesia	33,000
11	Mekong	Thailand,Cambodia,Laos, Vietnam	23,000


re)

- Red ： Rivers in Asian Countries
- Yellow ： **Rivers in the South China Sea** (this study)

→ There are few modeling studies on MP (microplastic) transport in the SCS

- **High concentrations of MP pollution** were found in the Pearl River estuary (Lam et al., 2020) and Pasig River mouth (Emmerik et al., 2020)

✓ **It is necessary to accurately evaluate the transport processes of MPs derived from major rivers in the SCS**

Objectives

Outline

We aim to answer the question on the fate of MPs derived from major rivers in the SCS by using a 3D ocean modeling technique coupled with a Lagrangian particle tracking model.

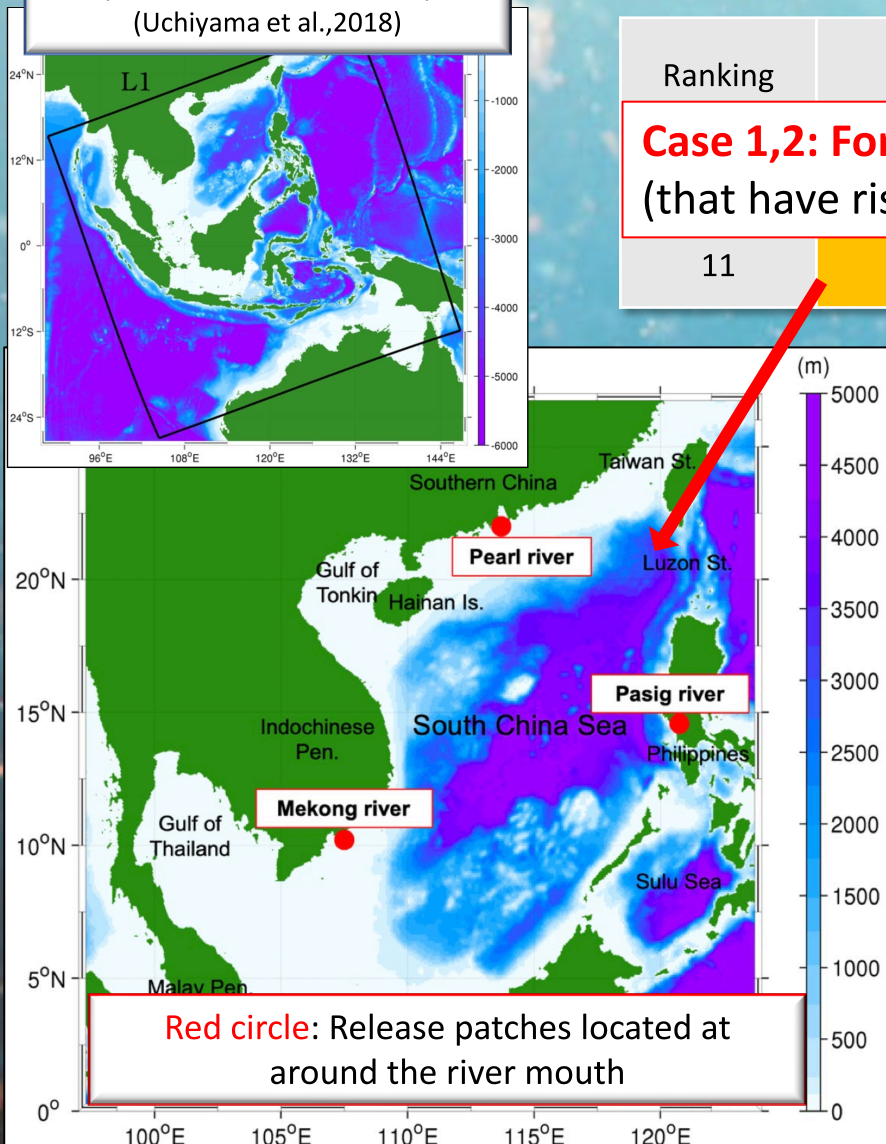
Main Objectives

1. **Evaluate 3D transport patterns of MPs in and around the SCS along with possible driving mechanisms**
2. **Quantify the rate of MPs originating from the SCS that beached, remained in the SCS, and flowed out to the surrounding seas.**

Contents

Configuration of particle tracking experiment

HYCOM-ROMS model
(Grid resolution: 5km)
(Uchiyama et al.,2018)



Ranking	Rivers	Country	Mass input estimate (tons・year^{-1})
11	Mekong	Thailand, … Vietnam	

Case 1,2: For buoyant MPs
(that have rising velocity)

Case 3: For non-buoyant MPs
(fully transported passively by the 3D ocean currents)

(Lebreton *et al.*, 2017 , Nat…)

case	1.Buoyant MPs	2. Buoyant MPs + Stokes drift	3. Passive MPs
Rising velocity	2 mm/s	10mm/s	–
Release depth	0.5m		
Number of patches	3		
Diameter of patches	25 km		
Release period	1/1/2012-12/31/2014 **(For 3years)**		
Release interval	12 hours		
Release time	2922		
Total number of particles	1,407,264	1,380,960	1,131,072

Configuration of particle tracking experiment

$$\frac{\partial}{\partial \tau} \boldsymbol{X}_n(\tau, \mathbf{a}) = \mathbf{U}_n(\tau, \mathbf{a})$$

$$\mathbf{U}_n(\tau, \mathbf{a}) = (\boldsymbol{u} + \boldsymbol{u}^{St})[\boldsymbol{X}_n(\tau, \mathbf{a}), \boldsymbol{t}_n + \tau] + w_{MP} \cdot e_1$$

$\mathbf{U}_n(\boldsymbol{\tau}, \boldsymbol{a})$: the 3D velocity of the n-th Lagrangian particle

$\boldsymbol{X}_n(\tau, \mathbf{a})$: the 3D position of the n-th Lagrangian particle

a: the initial position of the particle of interest

τ: the elapsed time

$\mathbf{u}[\boldsymbol{x}, \boldsymbol{t}]$: the 3D Eulerian velocity of HYCOM-ROMS model outputs at a given location x and time t

$\mathbf{u}^{St}[x, t]$: the Stokes Drift velocity at a given location x and time t

(1) Buoyant MPs forced by the 3D currents

δ_{MP}=1mm: which has been most frequently observed in the open ocean, less affected by Stokes Drift.

(2) Buoyant MPs forced by the 3D currents with linearly added Stokes drift

δ_{MP}=5mm: larger MPs that are affected by Stokes drift

(3) Non-buoyant MPs that are fully transported passively by the 3D currents

Small-sized MPs have relatively large surface areas and may be susceptible to **biofouling and material deposition.**

Rising velocity of MPs

w_{MP}=0.002 · δ_{MP}

(Reisser et al., 2015)

w_{MP}: Rising velocity of MPs (m/s)

δ_{MP}: MP size (mm)

Stokes Drift velocity

$$\mathbf{u}^{St} = \frac{A^2 \sigma}{2 sinh^2(kD)} \cosh(2k(z+h))\boldsymbol{k}$$

$$\sigma = \sqrt{gktanh\,(kD)}$$

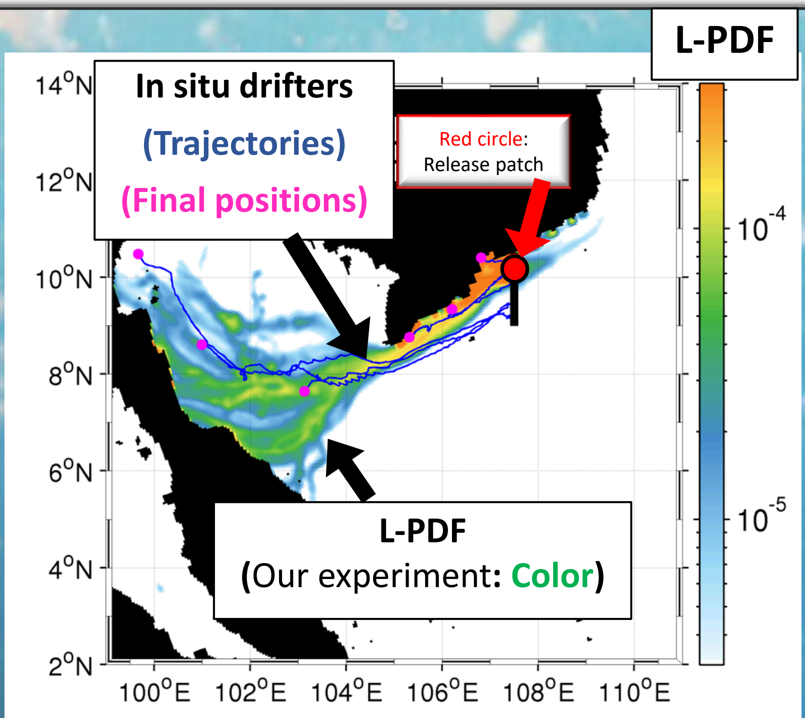
h(x) is the resting depth of the ocean; A is the wave amplitude; k is its wave number vector and k is its magnitude;

A, k, σ were calculated using the GWM dataset, a global wave model of JMA.

Larger MPs (δ_{MP}>5mm) are much affected by Stokes Drift (Iwasaki et al., 2017)

Validation of particle tracking experiments

In-situ Surface drifter (observed) trajectories (blue curves) and the final positions of them (magenta) on **Lagrangian PDFs (model, color)** averaged over the advection time of 120 days



Lagrangian PDF: two-dimensional probability density function of the particle displacement

- In situ surface drifters were transported within the extent of horizontal distribution of the high Lagrangian PDFs.
- Our particle tracking experiment was performed with **high accuracy for buoyant MPs** drifting on the surface layer.

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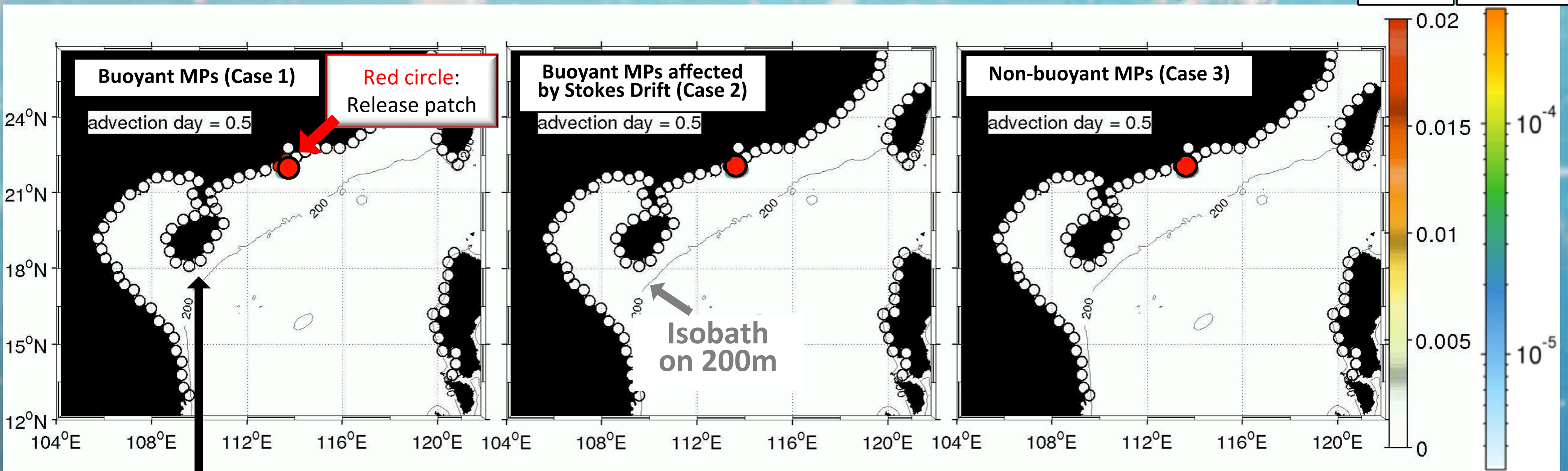
1. Introduction
2. Methods
3. **Transport of MPs in the SCS**
4. Conclusions

Transport of MPs in a monthly scale

Destination Strength (circles) and L-PDFs (colors) within the advection time of 30 days

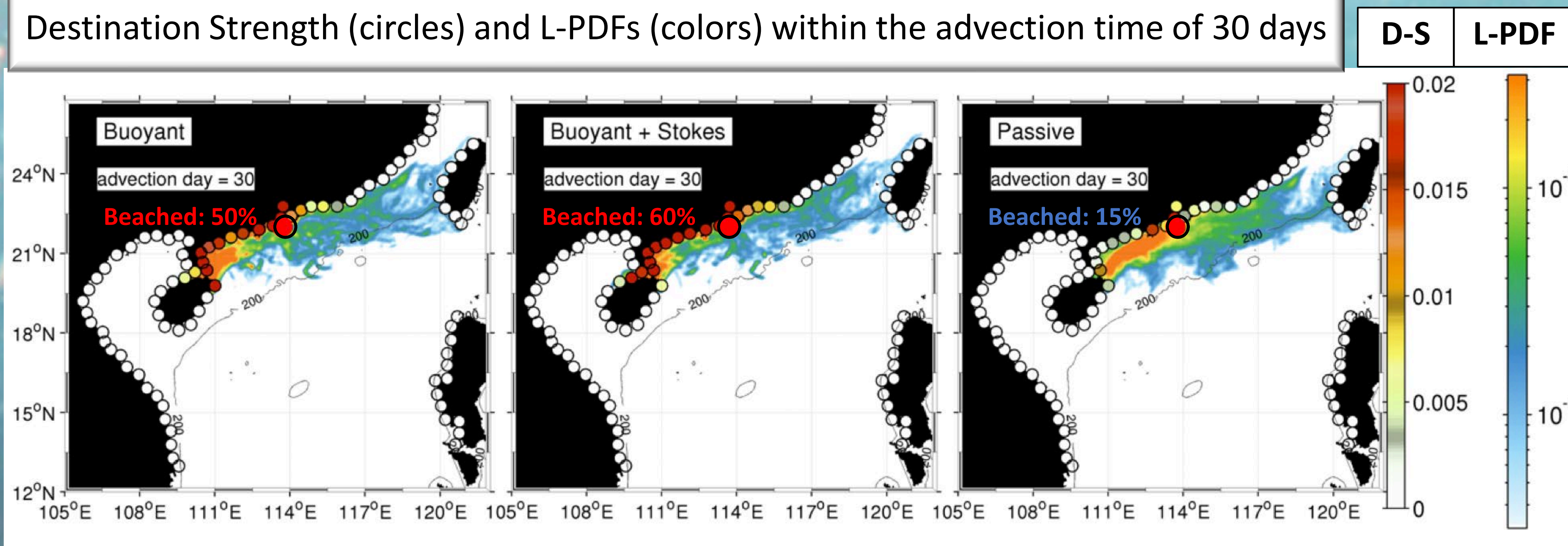


Destination Strength: the probability of Lagrangian particles transported from a release patch to a patch site

- The destination strengths are very high in the shore of southwestern China in Case 1 and 2 rather than Case 3.

Transport of MPs in a monthly scale

Destination Strength (circles) and L-PDFs (colors) within the advection time of 30 days



- Approximately 50%(Case 1)-60% (Case 2) of buoyant MPs derived from Pearl River are beached within 30 days.
- Beaches are the major destination of buoyant MPs derived from Pearl River and Mekong River (not shown)
- Wave effect (as Stokes drift) is modest on transport in the SCS.

Transport of MPs in a seasonal scale

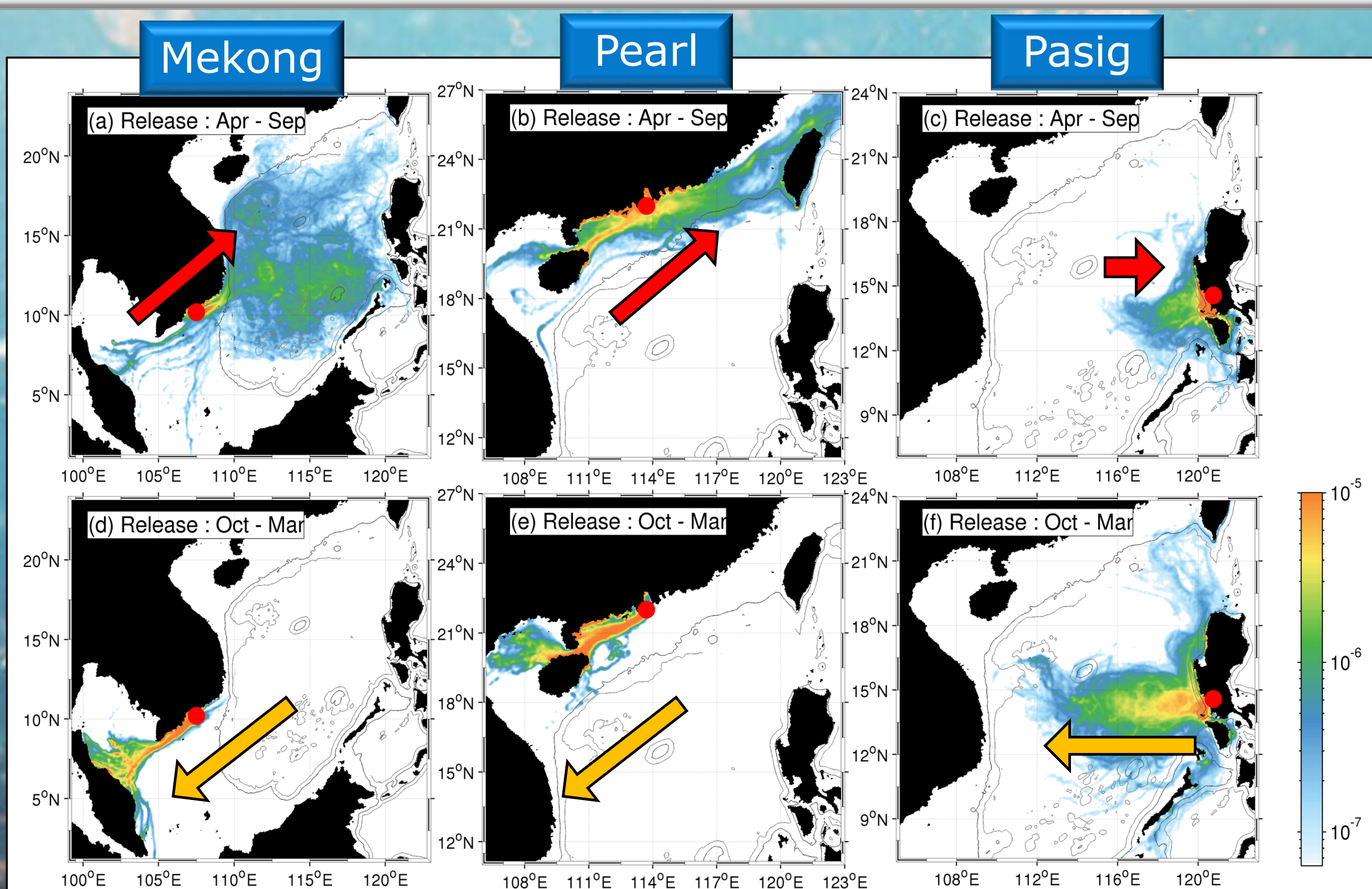
Lagrangian PDFs (Case 1) averaged over the advection time of 100 days

Released: Apr - Sep

Southwesterly monsoon

Released: Oct - Mar

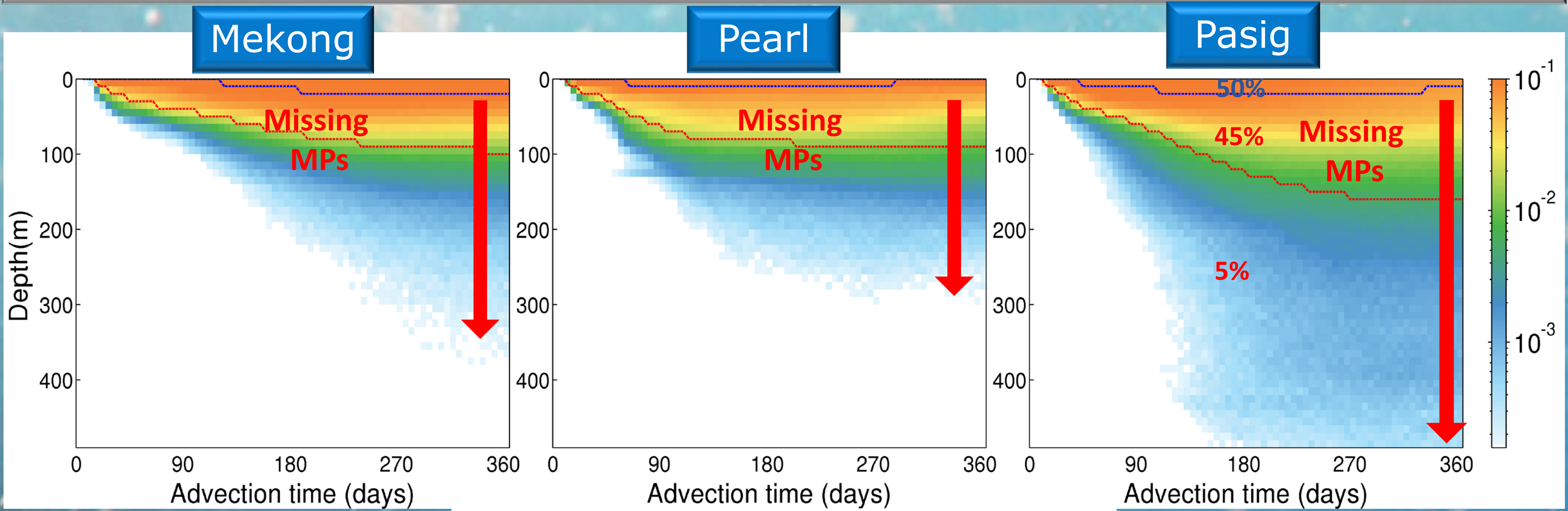
Northeasterly monsoon



- The transport of MPs in the SCS is obviously affected **by seasonally varying circulation system** driven by the *monsoon* in the SCS.

Vertical distribution of *non-buoyant* MPs

Hovmöller diagrams of the vertical distribution of Lagrangian PDF (Case 3)



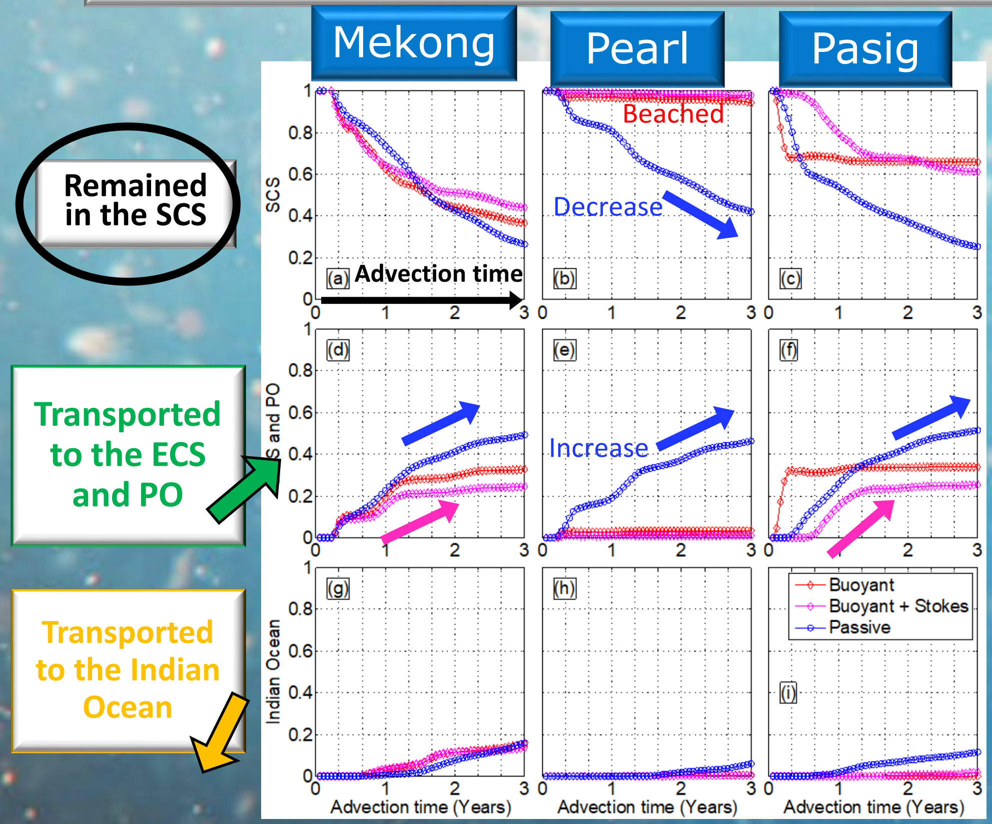
Blue : 50% tiles, Red : 95% tiles

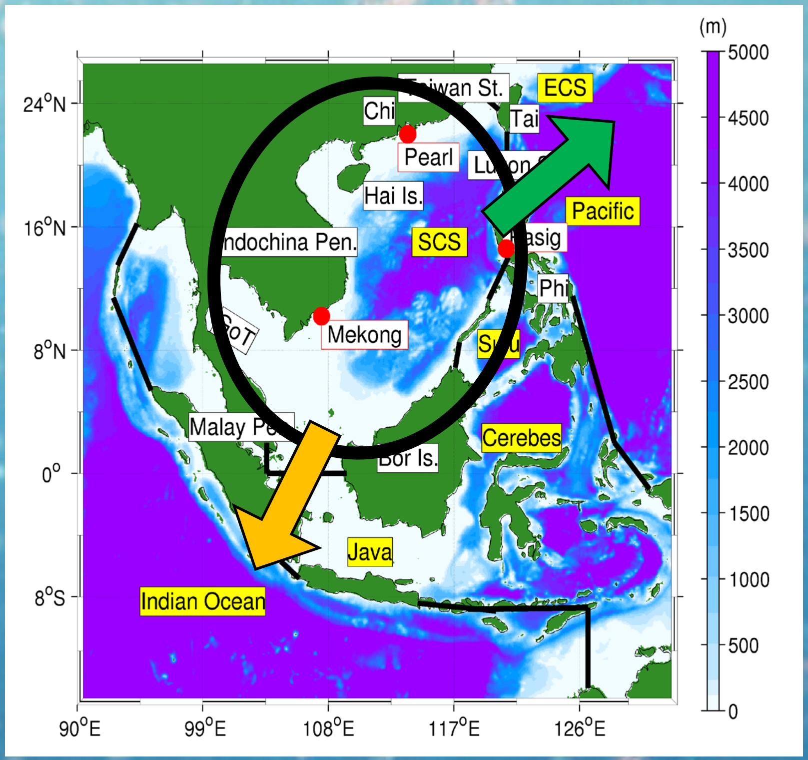
- Buoyant MPs (Case 1 and 2) are distributed at surface.
- Approximately 50% of *non-buoyant* MPs (Case 3) are distributed within 20 m from the surface (above blue lines).
- The other 50 % are transported to depths of several tens of meters (between blue and red lines) or deeper (below red lines) (<u>roughly in the surface mixed layer</u>) or (<u>below the mixed layer</u>).

More than a half of non-buoyant MPs might become "Missing MPs" that disappeared from surface.

Destinations of the river-derived MPs

The fraction of remained and transported MPs (released in 2012) for the advection time up to 3 years





- Non-buoyant MPs (Blue lines) are continuously transported to the surrounding seas.
- Buoyant MPs (Red and Magenta lines) that don't beached are also transported to the surrounding seas.

→ **The SCS is a major emission source of MPs to the surrounding seas.**

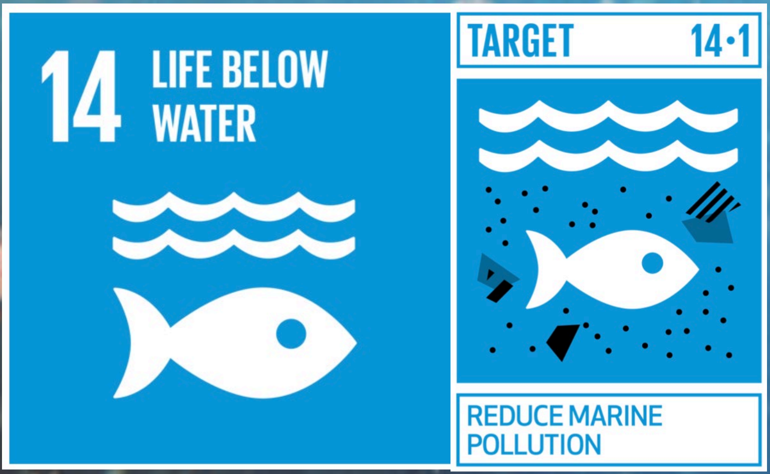
Contents

Conclusions

Main Conclutions

1. **Beach is a major destination of river-derived Buoyant MPs in the SCS.**
2. **The direction of prevailing monsoon is an important factor for regional transport of MPs in the SCS.**
3. **More than a half of non-buoyant MPs might become "Missing plastics" that are disappeared from ocean surface.**
4. **The SCS is a major source of MPs to the East China Sea & Pacific Ocean that are the hotspots of MP contamination.**

SDGs



#BeatPlasticPollution

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Fate of river-derived microplastics from the South China Sea: Sources to surrounding seas, shores, and abysses☆

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A R T I C L E I N F O

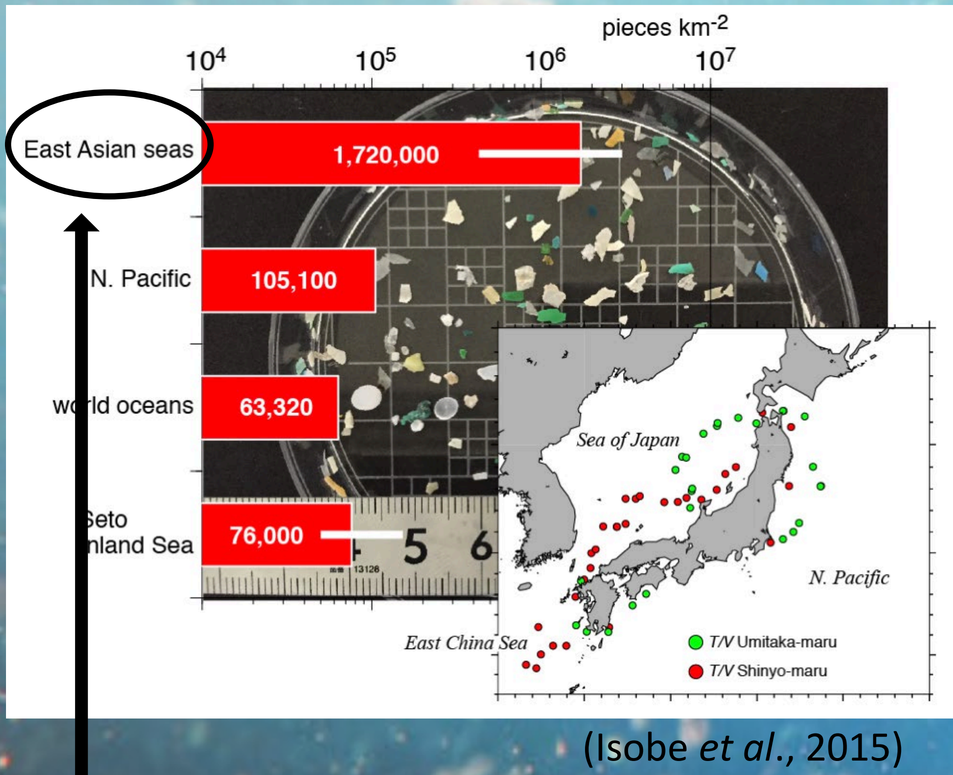
Keywords:
River-derived microplastics
Oceanic transport and dispersal
The south China Sea
Lagrangian particle tracking model
ROMS

A B S T R A C T

Microplastics (MPs) in the ocean have been widely recognized as causing global marine environmental problems. To gain a quantitative and comprehensive understanding of oceanic MP contamination, detailed numerical Lagrangian particle tracking experiments were conducted to evaluate the regional oceanic transport and dispersal of MPs in the South China Sea (SCS) derived from three major rivers, Pearl (China), Mekong (Vietnam), and Pasig (the Philippines), which are known to discharge large amounts of plastic waste into the SCS. As previous field surveys have suggested, MP contamination spreads from the surface to the deeper ocean in the water column, we thus considered three types of MPs: (1) positively buoyant (light) MPs, (2) positively buoyant (light) MPs with random walk diffusion, and (3) full 3-D tracking of non-buoyant MPs that are passively transported by ambient currents. Transport patterns of these MPs from the three rivers clearly showed the intra-annual variability associated with seasonally varying circulations driven by the Asian monsoons in the SCS. Many MPs floating during the prevailing southwest monsoon are transported to the northwest Pacific Ocean and the

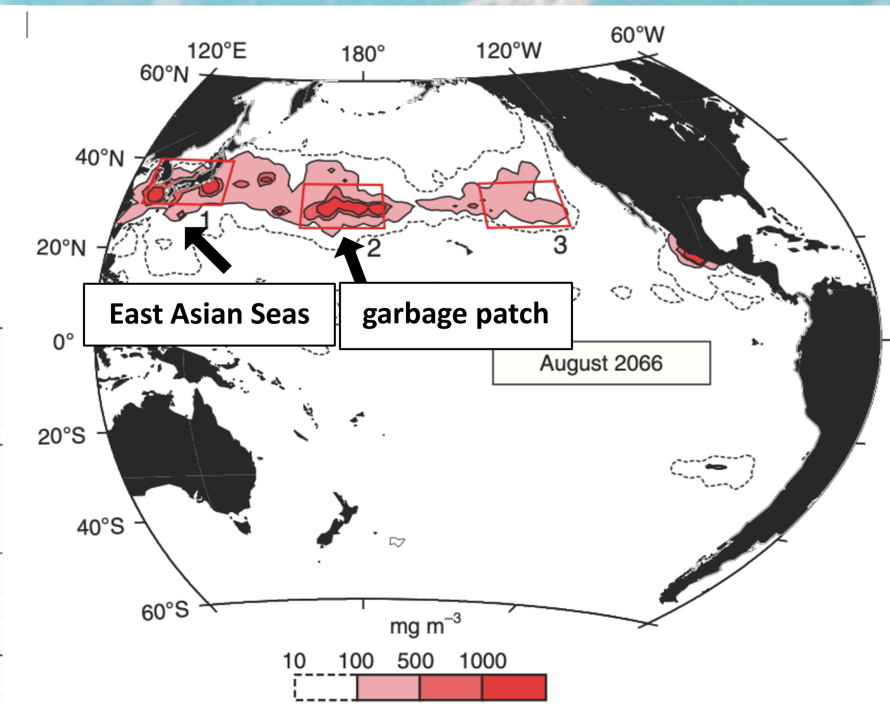
Introduction

Field sampling of MPs



(Isobe *et al.*, 2015)

Numerical Simulation

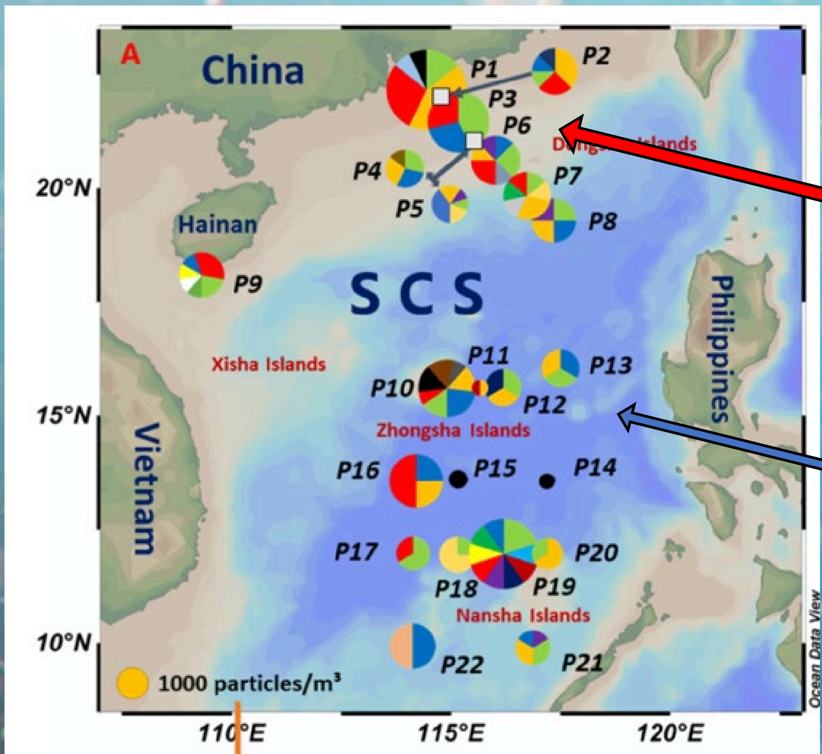


(Isobe *et al.*, 2019 Nature)

- **East Asian seas** have one of the highest contaminations of MPs in the world (Isobe *et al.*, 2015).
- It is also reported that **the North Pacific Ocean** is also highly contaminated and called **"garbage patch"** even though it is **very far from emission sources**.
- Asian-origin MPs seem to greatly affect the distribution of MPs in the northern hemisphere.

Introduction

Field sampling of MPs in the SCS



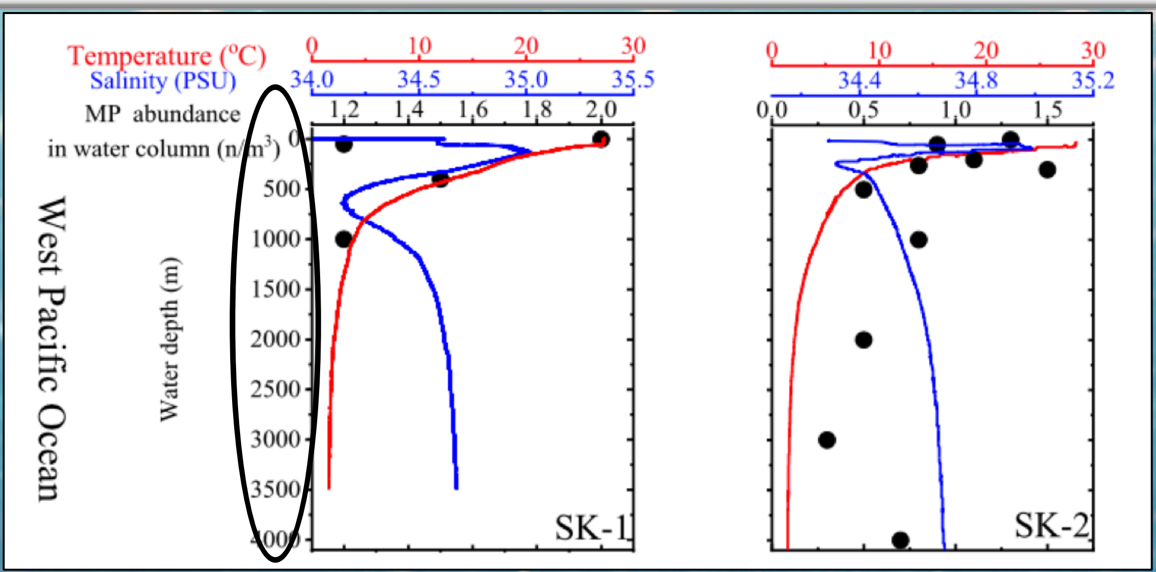
Cai *et al*. (2018)

- **High concentrations of MP pollution** were found in the coastal areas of southern China owing to **the influence of the Pearl River-derived MPs** (Cai et al., 2018; Lam et al., 2020).
- **MP pollution in the central SCS is not as severe** as that in MP hotspots such as the coastal SCS (Cai et al., 2018), the ECS (Zhang et al., 2020), and the Japan Sea (Isobe et al., 2015).

✓ **It is necessary to accurately evaluate the transport processes of MPs derived from major rivers in the SCS and their possible remote influences on the surrounding seas.**

Introduction

Field sampling of MPs in the deep sea in the Pacific Ocean



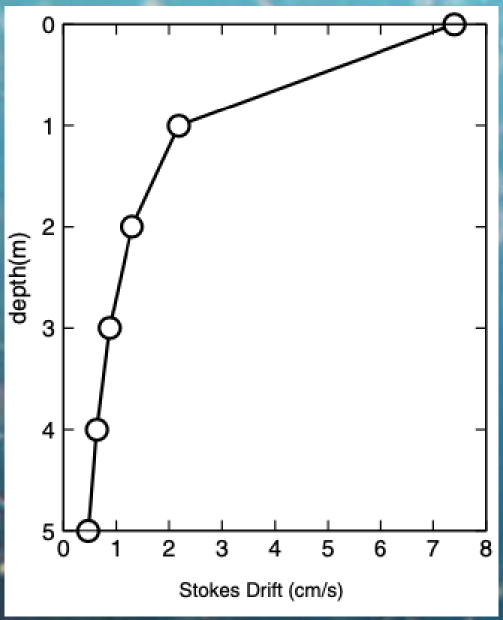
(Li *et al.*, 2020)

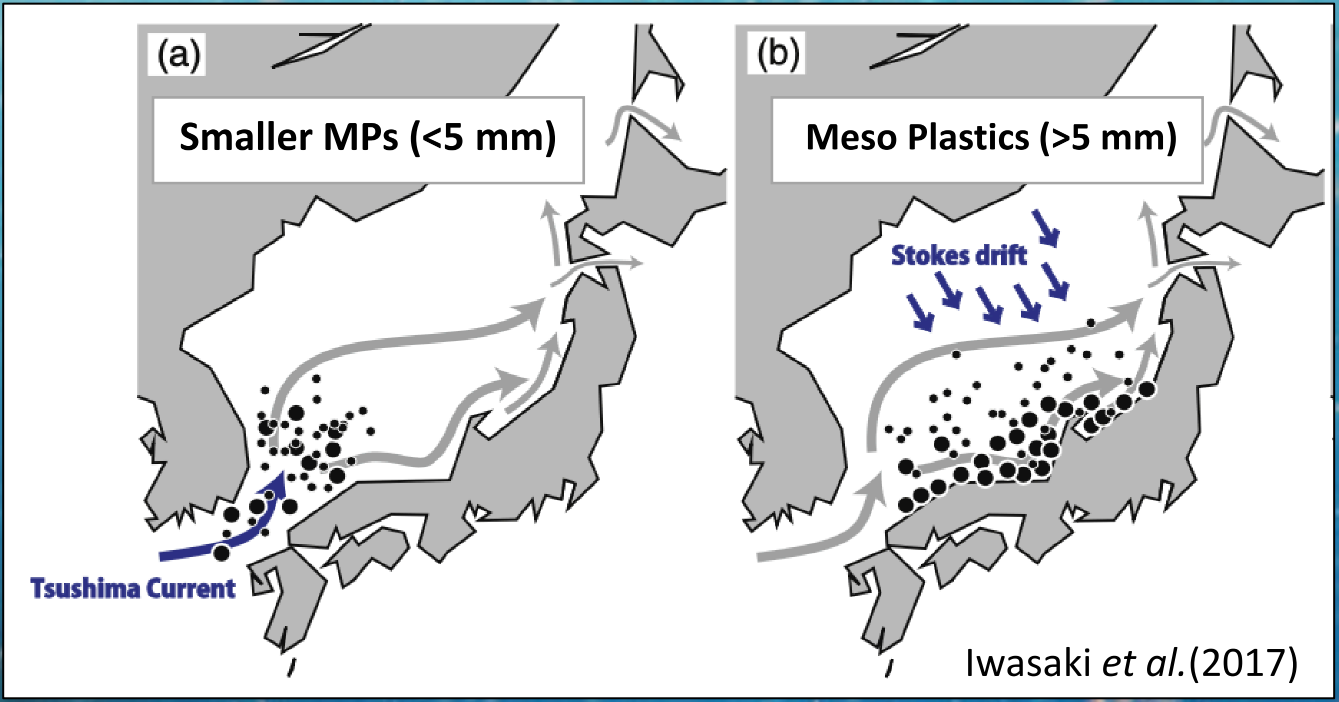
- MPs have occasionally been observed in the deep ocean at depths ranging **from several hundred meters to several thousand meters** (Li et al., 2020) .
- The top 5 m of the SCS contained around 700 tons of plastics, which is one to four orders of magnitude smaller than the reported emission (Cai et al., 2018) .
  → **"Missing Plastics" that disappeared from surface.**
- "Missing Plastics" make the matter of ocean MPs more complicated because once they are transported to the deep ocean, it is hard for us to observe and collect.

Introduction

Particle tracking simulation in the Japan Sea (Iwasaki *et al.* 2017)

Stokes drift in Japan sea





- Meso-plastics (>5 mm) are more affected by Stokes drift than Smaller MPs (<5 mm).
- Stokes drift may be a significant factor for larger plastic particles.

Configuration of particle tracking experiment

$$\frac{\partial}{\partial \tau}\boldsymbol{X}_n(\tau, \mathbf{a}) = \mathbf{U}_n(\tau, \mathbf{a})$$

$$\mathbf{U}_n(\tau, \mathbf{a}) = (\boldsymbol{u} + \boldsymbol{u}^{St})[\boldsymbol{X}_n(\tau, \mathbf{a}), \boldsymbol{t}_n + \tau] + w_{MP} \cdot e_1$$

$\mathbf{U}_n(\tau, \boldsymbol{a})$: the 3D velocity of the n-th Lagrangian particle

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$\mathbf{u}[x, t]$: the 3D Eulerian velocity of HYCOM-ROMS model outputs at a given location x and time t

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① Buoyant MPs forced by the 3D currents

δ_{MP}=1mm: which has been most frequently observed in the open ocean, less affected by Stokes Drift.

② Buoyant MPs forced by the 3D currents with linearly added Stokes drift

δ_{MP}=5mm: larger MPs that are affected by Stokes drift

③ Non-buoyant MPs that are fully transported passively by the 3D currents

Small-sized MPs have relatively large surface areas and may be susceptible to **biofouling and material deposition.**

Rising velocity of MPs

w_{MP}=0.002 · δ_{MP}

(Reisser et al., 2015)

w_{MP}: Rising velocity of MPs (m/s)

δ_{MP}: MP size (mm)

Stokes Drift velocity

$$\mathbf{u}^{St} = \frac{A^2 \sigma}{2 sinh^2(kD)} \cosh\left(2k(z+h)\right)\boldsymbol{k}$$

$$\sigma = \sqrt{gktanh\,(kD)}$$

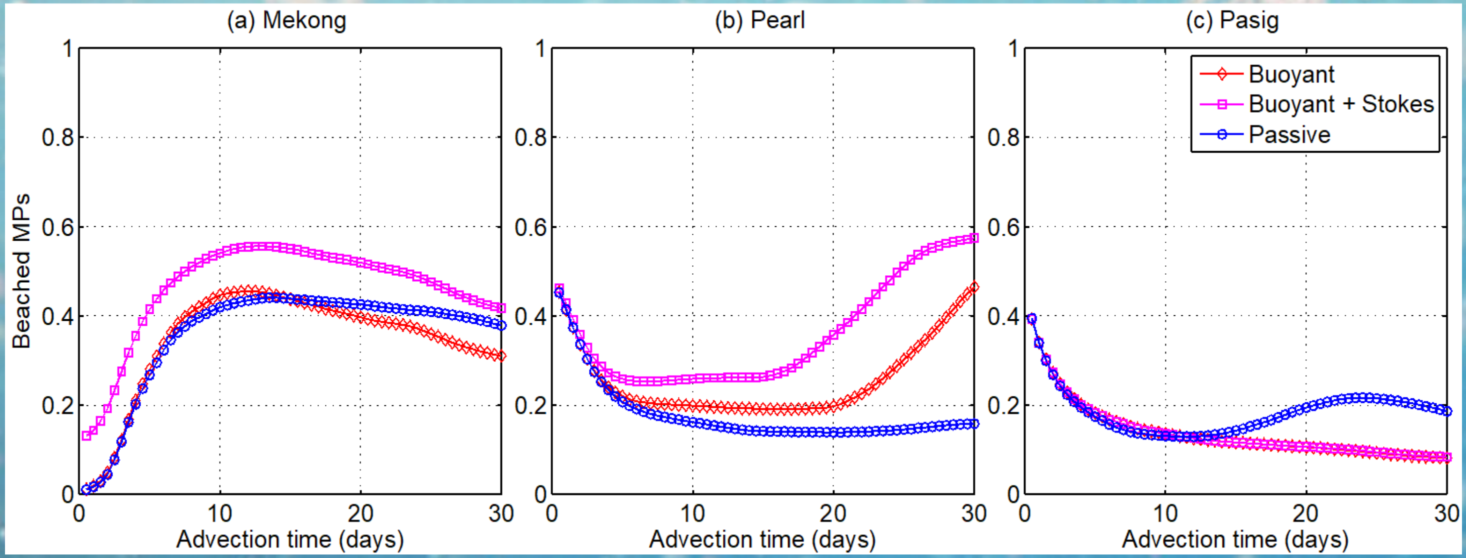
h(x) is the resting depth of the ocean; A is the wave amplitude; k is its wave number vector and k is its magnitude;

A, k, σ were calculated using the GWM dataset, a global wave model of JMA.

Larger MPs (δ_{MP}>5mm) are much affected by Stokes Drift (Iwasaki et al., 2017)

Transport of MPs within a monthly scale

The fraction of beached MPs for the advection time of up to 30 days

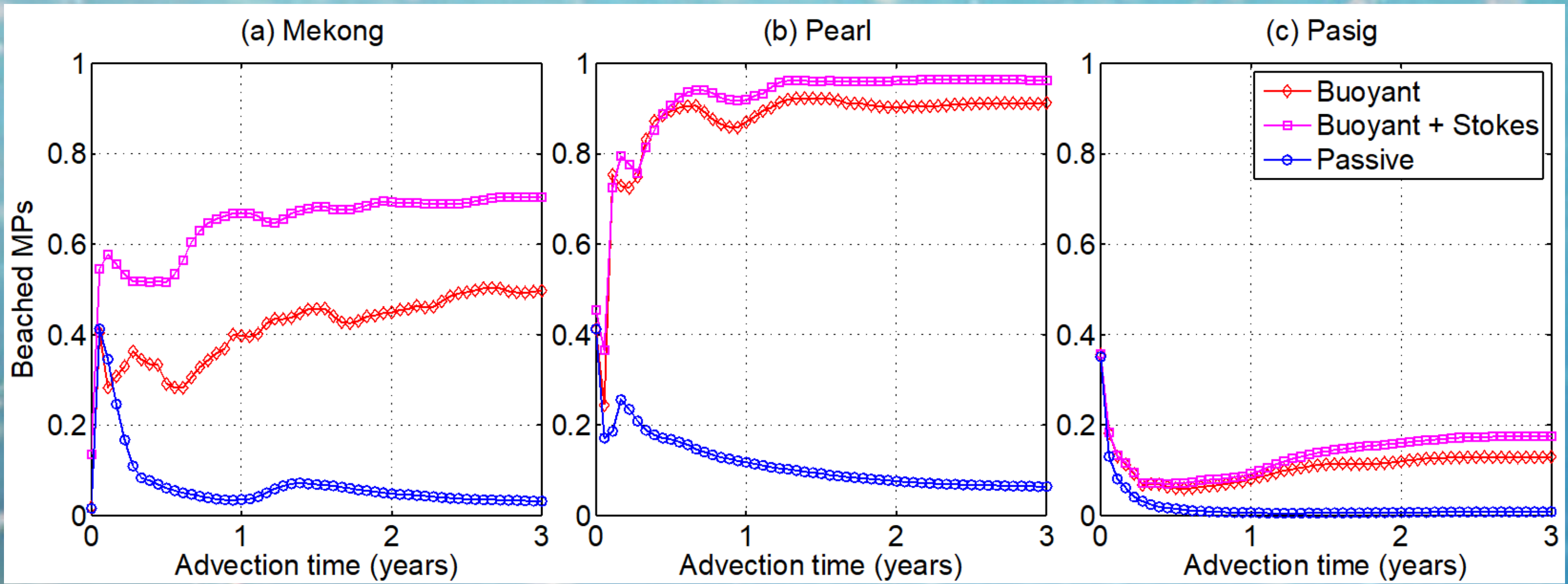


➢ In our analysis, the particles reaching a grid cell with the representative shallow water depth of 20 m, which pre-defined the minimum depth set in the HYCOM-ROMS model, are automatically deemed “beached.”

- Approximately 50%(Case 1)-60% (Case 2) of buoyant MPs derived from Pearl River are beached within 30 days.
- Stokes drift toward the continent further increases the beached rate.

Long-term transport of MPs

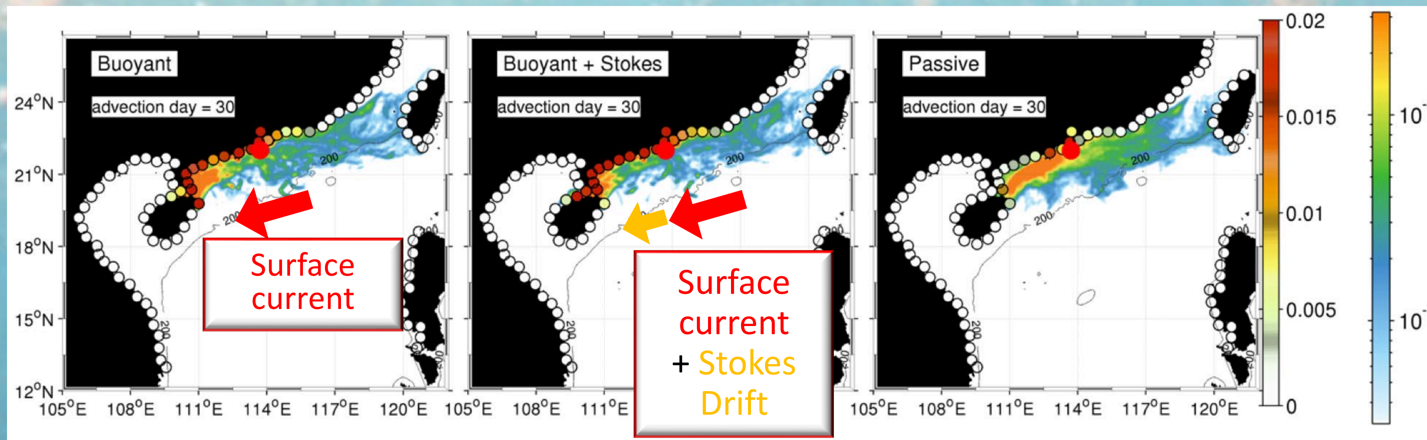
The fraction of beached MPs (released in 2012) for the advection time of up to 3 years



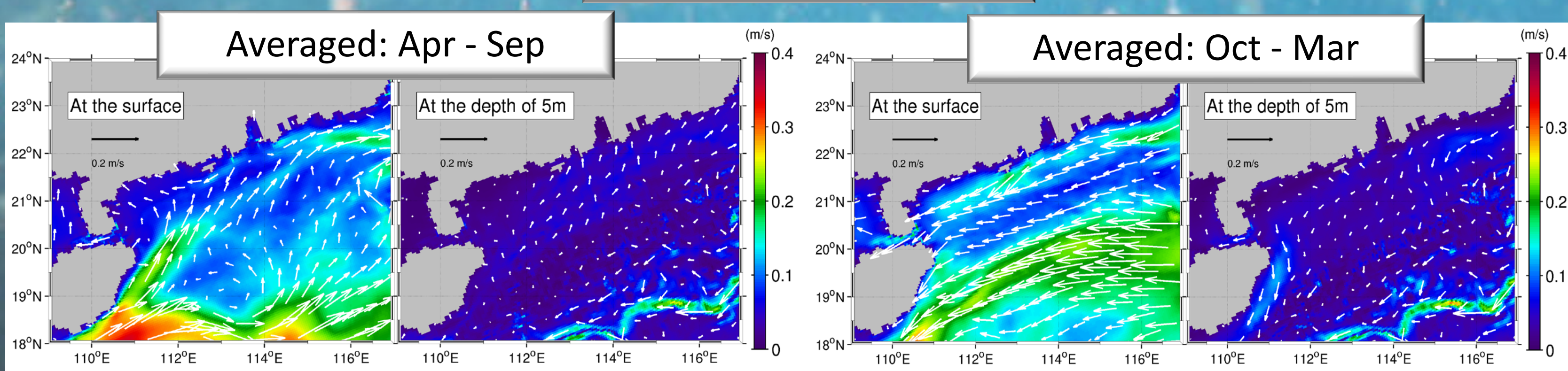
- Most of the buoyant MPs (Red and Magenta lines) originating from Pearl River (approximately 90%) and Mekong River (50% in Case 1 and 70% in Case 2) are beached within a year.

→ **Beach is the main destination of buoyant MPs derived from Mekong River and Pearl River**

Transport of MPs within a monthly scale



Horizontal velocity (m/s)



- The buoyant MPs originating from Pearl River tend to be pushed toward the shore by wind-induced currents more pronouncedly than the non-buoyant MPs.
- Non-buoyant MPs are vertically transported and less influenced by surface currents.

Transport of MPs in a seasonal scale

Lagrangian PDFs of the MPs released from April to September on the advection time of 180 days

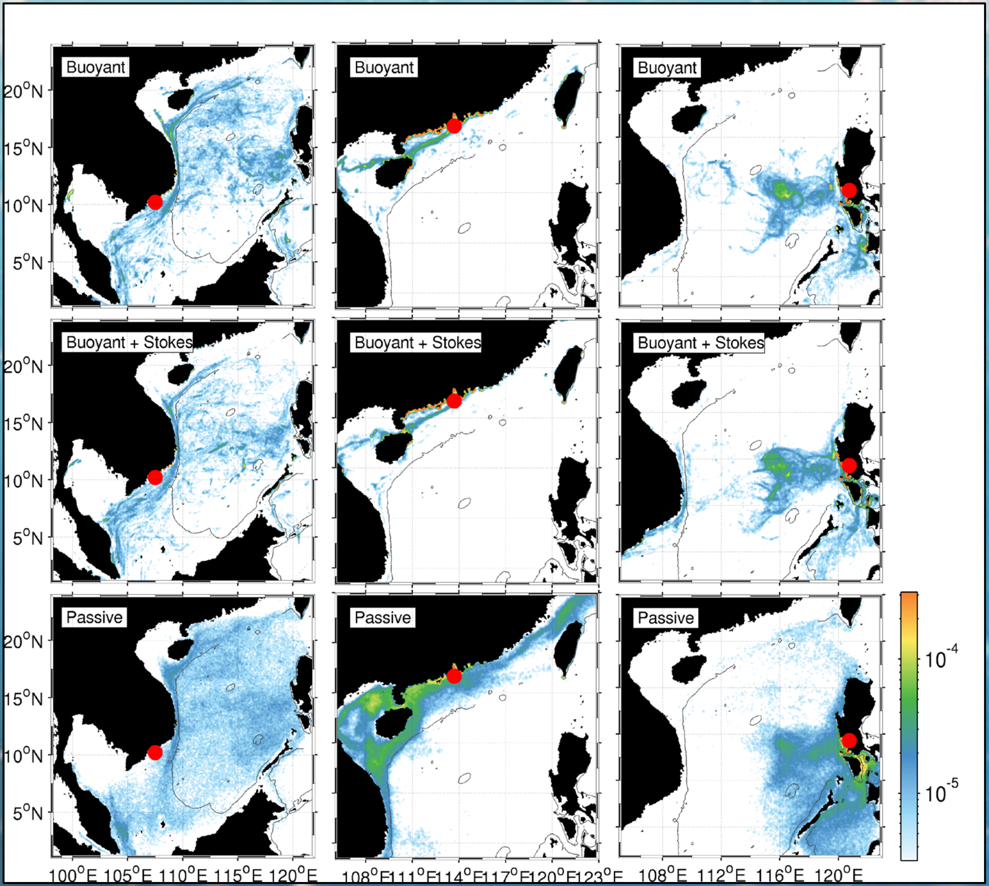
Buoyant MPs

Stokes Drift

Buoyant MPs +Stokes Drift

Buoyancy

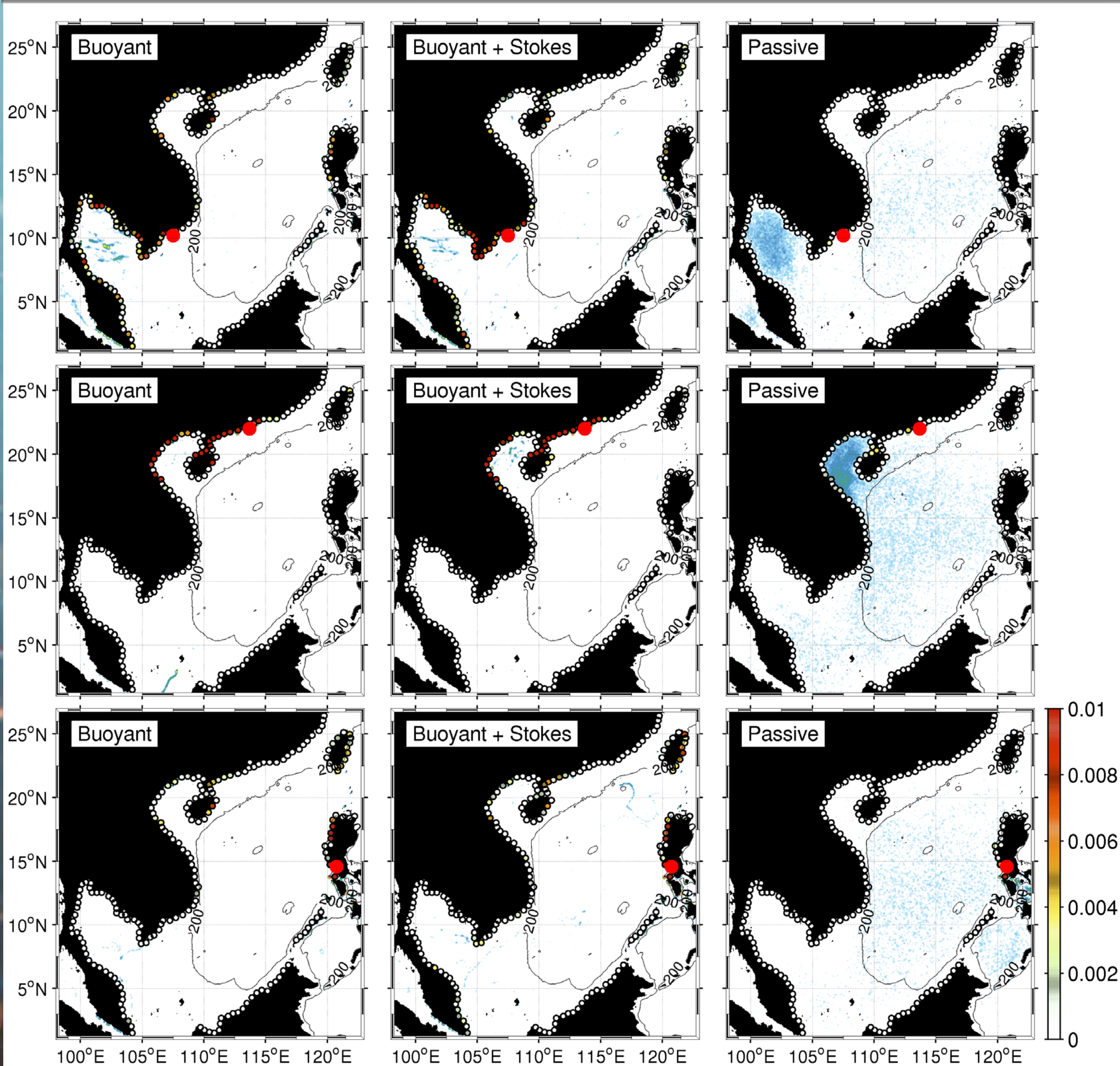
Neutral and Fully passive MPs



- The transport of MPs in the SCS is not much affected by Stokes Drift.
- The horizontal dispersal of the non-buoyant MPs is wider than that of the buoyant MPs

Long-term transport of MPs

Destination strength and Lagrangian PDFs on the advection time of 3 years



- Long-term advected MPs are rarely remain in the SCS.
- Almost all MPs in Case 1 and Case2 are beached.
- Non-buoyant MPs remaining in the SCS mostly stay in the Gulf of Thailand, Gulf of Tonkin, and central SCS.