NOWPAP MERRAC

Northwest Pacific Action Plan
Marine Environmental Emergency Preparedness and Response
Regional Activity Centre

1312-32, Yuseong-daero, Yuseong-gu, Daejeon 34103, Republic of Korea
Korea Research Institute of Ships and Ocean Engineering (KRISO)
Tel: (+82-42) 866-3638, FAX: (+82-42) 866-3630
E-mail: nowpap@kriso.re.kr
Website: http://merrac.nowpap.org

Review and analysis of floating marine litter prediction models in the NOWPAP region

Regional Seas

NOWPAP MERRAC

Northwest Pacific Action Plan
Marine Environmental Emergency Preparedness and Response
Regional Activity Centre

1312-32, Yuseong-daero, Yuseong-gu, Daejeon 34103, Republic of Korea
Korea Research Institute of Ships and Ocean Engineering (KRISO)
Tel: (+82-42) 866-3638, FAX: (+82-42) 866-3630
E-mail: nowpap@kriso.re.kr
Website: http://merrac.nowpap.org

Review and analysis of floating marine litter prediction models in the NOWPAP region

Regional Seas

First Published in 2018
by Marine Environmental Emergency Preparedness and Response
Regional Activity Centre
the Northwest Pacific Action Plan (NOWPAP MERRAC)
1312-32, Yuseong-daero, Yuseong-gu, Daejeon 34103, Republic of Korea
Korea Research Institute of Ships & Ocean Engineering (KRISO)

Printed in Republic of Korea by Sinkwangsa

ISBN 978-89-93604-39-9

For bibliographical purposes this document may be cited as:
MERRAC Technical Report No. 36. Review and analysis of floating marine litter prediction models in the NOWPAP region, NOWPAP MERRAC, 2018, pp. 32.

PREFACE

Marine litter can cause serious environmental, economic and health problems, and the concerns have been increasing in the NOWPAP region without exception. Particularly floating marine litter is being treated as a regional issue as it travels to the neighboring countries by winds and currents. Thus, it must be addressed through both national and regional initiatives and also data and information should be shared and exchanged. Various projects and activities have been implemented in the NOWPAP region, and several guidelines, brochures and regional reports on marine litter monitoring and management in different sectors were published as listed below:

- Guidelines for Monitoring Marine Litter on the Seabed in the Northwest Pacific Region (2007)
- Guidelines for Providing and Improving Port Reception Facilities and Services for Ship-Generated Marine Litter in the Northwest Pacific Region (2007)
- Sectoral Guidelines for Marine Litter Management: Fishing, Commercial Shipping, Recreational Activities, Passenger Ships (2007)
- Brochure on Sea-Based Marine Litter: Problem & Solution (2007)
- Regional Report on Sea-Based Marine Litter (2008)
- Marine Litter Management: The Approach of Incheon City, Korea (2008)
- Port Reception Facilities in the NOWPAP Region (2009)
- Report on the Technologies and Research Outcomes on Prevention, Collection and Treatment of Marine Litter in the NOWPAP Region (2010)
- Negative Impacts of Marine Litter in the NOWPAP Region: Case Studies (2013)
- Best Practices in dealing with Marine Litter in Fisheries, Aquaculture and Shipping sectors in the NOWPAP region (2015)
- Understanding of floating marine litter distribution in the NOWPAP region (2017)

As the next phase of the previous projects, a new regional project entitled ‘Review and analysis of floating marine litter prediction models in the NOWPAP region’ was proposed with an aim to identify the development status of the floating marine litter prediction systems in the NOWPAP region. This publication will try to share information on the prediction models that have been developed in the member countries of the NOWPAP region in order to analyze the behavior of the floating marine litter and parameterization of the floating marine litter characteristics. The main objective is to establish a plan for future development of a regional prediction model, which could be applied to predict the behaviors of floating marine litter, in order to eventually identify the floating marine litter trajectory and support the reduction and development of prevention measures of floating marine litter in the NOWPAP region.

It is believed that this publication will provide essential information and framework for reduction and prevention of floating marine litter in the NOWPAP region and the global community. It will eventually help to trigger actions to build a stronger regional cooperation system among the NOWPAP members. I would like to take this opportunity to express my sincere gratitude to all NOWPAP MERRAC Focal Points, Marine litter Focal Points and national expert for their support and contributions to the MERRAC activities.

Dr. Seong-Gil Kang
Director of NOWPAP MERRAC

Acknowledgments

This report has been prepared by the Marine Environmental Emergency Preparedness and Response Regional Activity Centre (MERRAC) of the Northwest Pacific Action Plan (NOWPAP) with inputs from the national experts of the NOWPAP members as agreed at the 18th MERRAC Focal Points Meeting and 20th NOWPAP Intergovernmental Meeting (IGM) in 2015. This study has been conducted as a part of activities within the framework of the NOWPAP Regional Action Plan on Marine Litter (RAP MALI), inter alia, upon the RAP MALI workplan for the 2016-2017 biennium. The nominated external expert, Prof. Yong Hoon Kim (West Chester University, USA) is first author of the report, and external expert Dr. Young Gyu Park (Korea Institute of Ocean Science & Technology, Korea) and MERRAC staffs (Dr. Seong Gil Kang, Dr. Jeong Hwan Oh, Ms. Joung-yun Lee, Ms. Siyeon Lee and Ms. Narae Yoon) contributed in the report. Also, this report was finalized with technical supports of the MERRAC Focal Points, NOWPAP Marine Litter Focal Points, NOWPAP Regional Coordinating Unit (RCU) and consultation of Ms. Yoon Young Back (former MERRAC staff).

Table of Contents

Chapter 1. Introduction

Marine litter is defined as any persistent solid material that has deliberately or accidently been released in rivers, coastal seas, or oceans. It is one of the major pollutants that is affecting the marine environments causing negative visual and aesthetic impacts (NOAA MDP, 2016). In addition, it could be a potential harm to marine life by ingestion or entanglement (NOAA MDP, 2014) or acting as a vehicle for invasive species (Ruiz et al., 1997).

Most marine litter remains suspended in the water column or floating at the surface for days or years. No matter how marine litter enters into the ocean (whether it is deliberately disposed or naturally drifted in the ocean); marine litter may travel a great distance by ocean currents and winds and end up accumulating on beaches or islands. Studying transport and fate of marine litter, thus, must consider winds and surface ocean currents.

Different from beach surveys on marine litter, it is a difficult task to examine movement of floating litter in the oceans, because floating objects are either too small to be detected by airplanes/satellites, or observers on vessels may pass over the floating debris during surveys, or because chances to detect floating objects are greatly reduced under the wavy conditions. Thus, scientists can apply a computer simulation technique to reproduce or predict winds and surface ocean currents that carry marine litter.

Modeling of marine litter transport is mostly simulated in an Eulerian-Lagrangian combined framework. The Eulerian perspective means that the wind and current velocities can be solved by discrete grids or nodes over time steps. And the Lagrangian approach is that the solutions, i.e., wind and current velocities, from those models are used to estimate the trajectory of the marine litter via particle tracking methods. Then, how to link these two, between the ocean circulation model results and marine litter tracking model is another important step in order to forecast the transport and fate of marine litter.

In this report, the state-of-the-art techniques applied in predicting floating marine litter will be reviewed. Important factors controlling the transport and fate of marine litter will be discussed in a computer simulation perspective. Case studies on computer simulation applied to the NOWPAP region will also be reviewed. In addition, some recommendations for development of a regional model will be listed at the end.

Chapter 2. Floating marine litter transport model

Fate of litter discharged into ocean is affected by various physical and oceanic factors. More explicitly, winds and currents depending on the shape of the object and the surface area exposed above the sea water primarily determine the trajectories of floating marine litter (Dohan and Maximenko, 2010). Buoyancy is one of the factors that should be considered to examine transportation of marine litter. The buoyancy is determined by the floating type and kind of marine litter, therefore, the effect of oceanic factor varies.

As the seasonality of the oceanic factors, ocean circulation models are commonly used to describe physical and thermodynamic processes in oceans. The Ocean circulation models include an Ocean General Circulation Model (OGCM), as well as Regional Ocean Circulation Model and Coastal Ocean Circulation Model. In order to elucidate the fate of litter discharged into ocean and search the origin of beached litter locally and globally, various studies using ocean circulation models and numerical models have been carried out. There are many numerical studies worldwide, but this report will focus only on the NOWPAP region and introduce a few examples conducted in the NOWPAP region and for the open ocean.

In the sea surrounded by Korea, Japan and Russia, the fate of marine litter was investigated using a numerical simulation of floating marine litter drift to investigate the effect of buoyancy ratio in the distribution of marine litter along the Japanese coast (Yoon et al. 2009). It utilizes ocean current and wind data from a numerical ocean circulation model and atmospheric circulation model. The results of the study showed that almost all marine litter released into the sea beaches or leaves the sea within 3 years through the Soya and Tsugaru Straits toward the northwestern Pacific. Almost all lighters originating from Japan beach along the Japanese coast, while almost all lighters from other countries beach along the coast of that country and the Japanese coast.

In Figure 2.1, the drifting routes of litter found in summer and winter, in a city located in the west coast of Japan, Niigata are shown. The target item was a disposable lighter which considered the buoyancy ratio depending on the floating types of lighter (diagonal, horizontal and vertical), with inputs from large cities and river basin. During summer (left side of Figure 2.1), the litter in Japanese coastline was mostly originated from upstream of the Tsushima Current. During the winter season, on the other hand, most of the litter on the Japanese coast was transported from the interior of the NOWPAP Sea area due to the effect of strong northwest wind. Simulated results showed consistency with the results of the beach surveys.

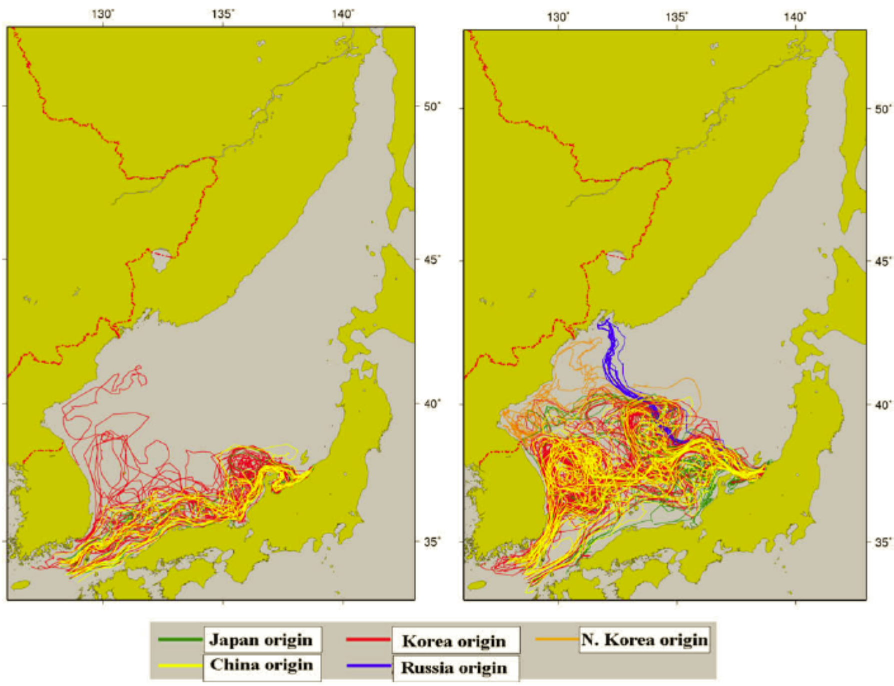


Figure 2.1 Drifting routes of litter (lighter) found in a city located in the west coast of Japan, Niigata, in summer (left) and winter (right) (Yoon et al 2009)

The residence time of deployed marine litter strongly depends on the buoyancy ratios, which could be controlled by relative contribution of ocean currents and wind (Yoon et al. 2009). Four different kinds of buoyancy ratios were applied in their simulation experiments. The buoyancy ratio was defined as the ratio of the cross sections of a floating litter normal to wind direction below and above the sea surface. The target items they tried to simulate include disposable lighters, plastic bottles, and plastic containers. Those three target items comprise almost 90% of floating marine litter (Yoon et al., 2009). The buoyancy ratio varies from 100% to 1% submerged. The disposal lighters show three floating types and have high buoyancy in diagonal (case A3), horizontal (case A2) and vertical (case A1) type in order. The buoyancy ratio of plastic container (case A4) and plastic bottle (case A5) are higher than disposal lighters. The simulation results using materials of different buoyancy ratio show that the residence time and beaching features strongly depend on the buoyancy ratio (Figure 2.2). With the lowest buoyancy ratio, litter mostly beaches along the Japanese coast due to the advection effect of the Tsushima current and the strong northwest wind. With an increase in the buoyancy ratio, beaching along Honshu of Japan increase due to the increasing pressure effects of northwest winds, in particular from late fall and early spring. The number of pieces of beached litter along the Russian coast increases due to the increasing pressure effect of northward winds during summer.

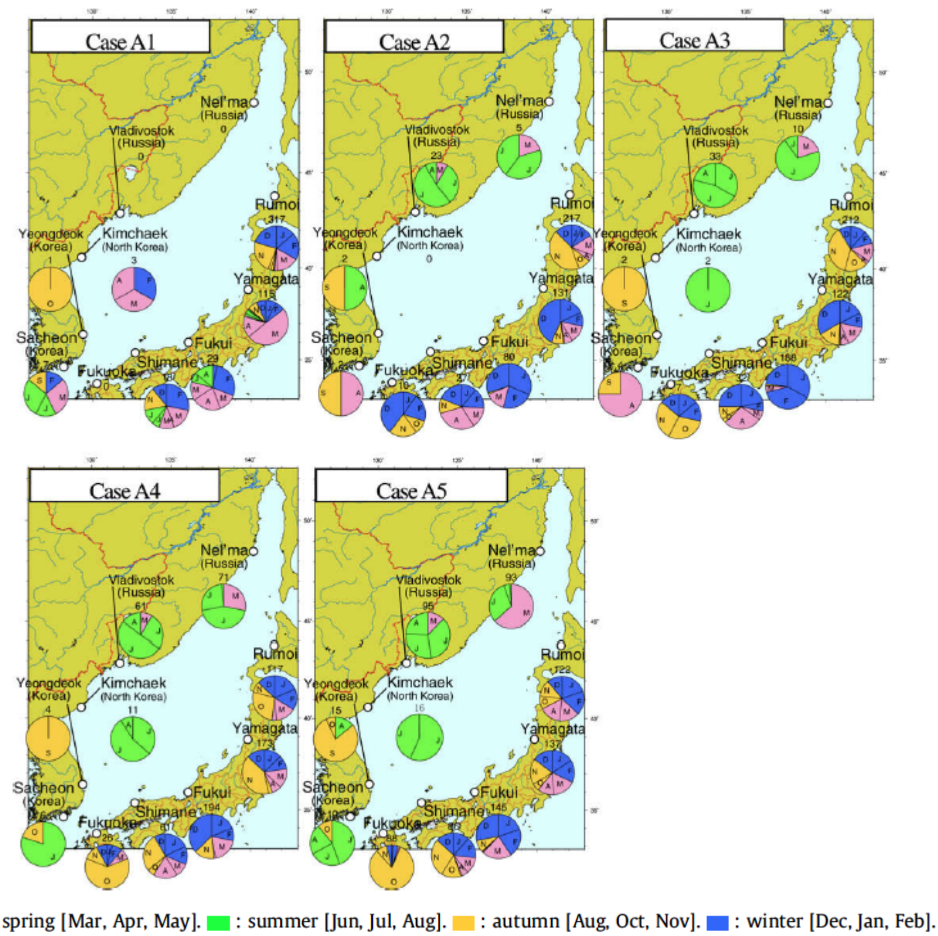


Figure 2.2. Beaching properties: lighters (Case 1-3), plastic container (Case 4), and plastic bottle (Case 5). Different colors represent data from different seasons (Yoon et al 2009)

The seasonal changes of numbers of beached litter were also investigated (Yoon et al. 2009). The results were analyzed in groups based on the origination of litter (e.g., litter originating from Korean beaches along the Korean and Japanese coasts). In detail, the beaching density is high along the entire Japanese coast during winter, while it is high along Kyushu and Yamaguchi coasts during spring and high along Akita, Aomori and Hokkaido in fall (Figure 2.3).

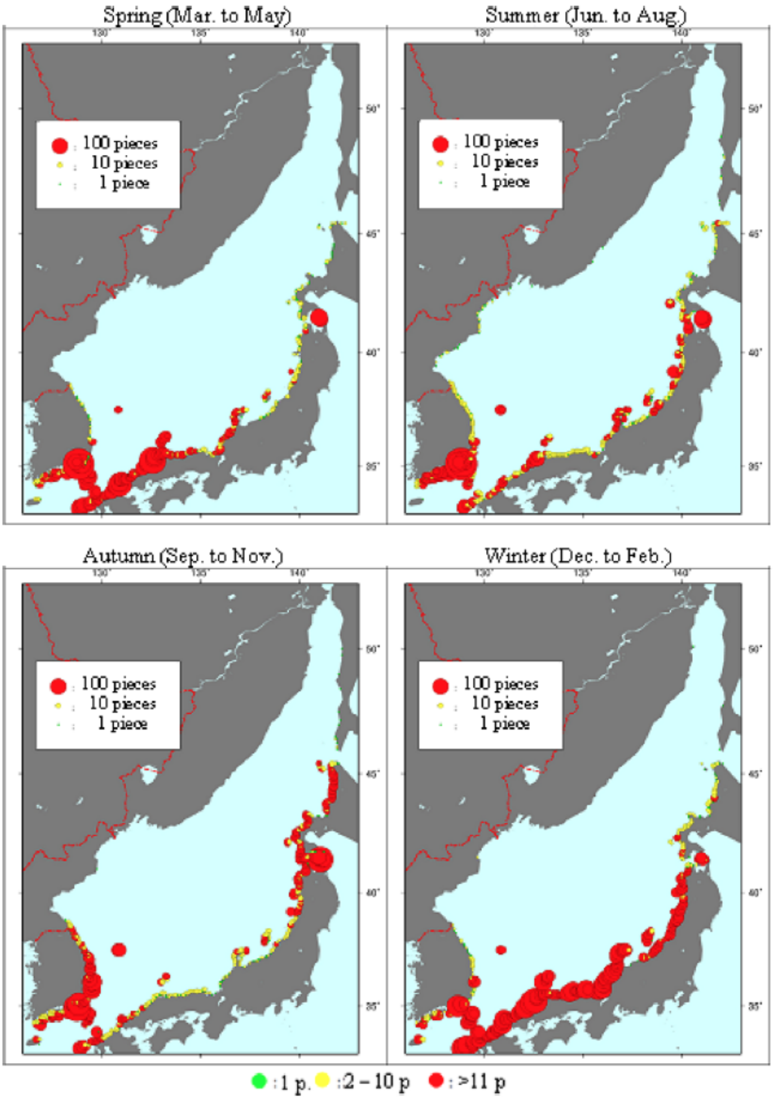


Figure 2.3. Seasonal changes of number of beached litter originating from Korea during 2003 - 2006. (Yoon et al 2009)

Their simulation results match with the beach surveys with regard to the country ratios of beached litter along the Japanese coast. It indicates that their simulation is suitable to understand the actual condition of drifting and beaching of floating marine litter, however, many issues remain unresolved. One of the suggestions for future improvement was the model velocities that advect litter. The velocity that advects floating litter is actually the velocity of a very thin surface layer, which is influenced by physical processes such as Langmuir circulation, turbulences and near inertial waves in the ocean mixed layer. Another improvement to make could be the wind pressure. The wind pressure effects on floating litter drift might be dependent on the litter shape, which has not been taken into consideration in their study.

In the area of Yellow Sea and East China Sea, the trajectories of satellite-tracked drifters were reproduced using a numerical particle tracking model study (Kako et al., 2010a). It used QuickSCAT/Seawinds data to derive surface currents, and both wind and currents data. The modeling results confirmed that the trajectories of the satellite-tracked drifters and numerical drifters show similar patterns in statistically significant way. During one of the model years (2007) when wind was relatively strong, the model was unable to reproduce the satellite drifter trajectory probably due to large error in estimating wind-induced leeway drift.

In that study, the authors collected the data showing the behavior of objects drifting in the actual ocean by tracking drifters (buoy) released in 2003, 2004 and 2007 (Fig. 2.4). Climatological surface current vectors averaged from June through November from a sigma-coordinated Princeton Ocean Model (POM) are also shown in Fig. 2.4. The comparison analysis confirmed that the drifter trajectories are consistent with the averaged surface currents.

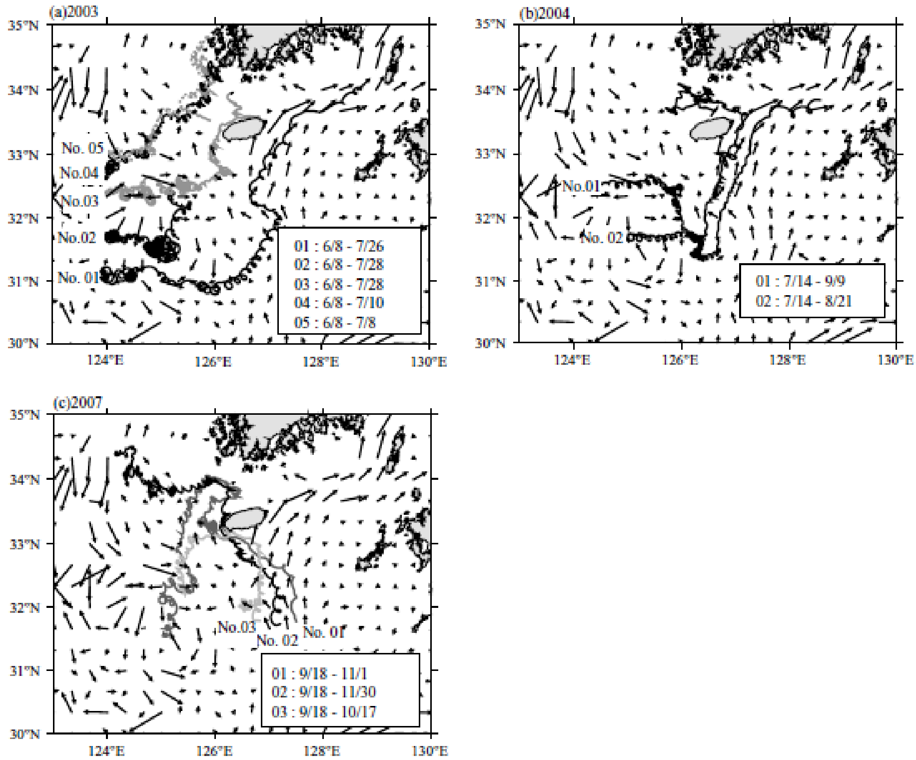


Figure 2.4. Trajectories of the drifters deployed in (a) 2003, (b) 2004 and (c) 2007. (Kako et al., 2010a)

Kako et al. (2010a) employed a particle tracking model approach using the formula below:

$$\mathbf{X}^{t+\Delta t} = \mathbf{X}^{t} + \mathbf{U}\Delta t + \frac{1}{2}\left(\mathbf{U}\cdot\nabla_H \mathbf{U} + \frac{\partial \mathbf{U}}{\partial t}\right)\Delta t^2 + R\sqrt{2K_h \Delta t}\,(\mathbf{i}, \mathbf{j}),$$

Where U is the current vectors, K_h is the diffusivity computed in the hydrographic model, i and j denote the unit vectors in the zonal (x) and meridional (y) direction, and R represents a random number with the average of 0 and standard deviation of 1, respectively. The results of the particle tracking show that the similarity between the modeled particle and observed buoy trajectories is significant in 2003 and 2004 (Figs. 2.4 and 2.5). They released 10,000 particles at the same time and the gray dots denote all 10,000 particles at the end of the modeling experiments.

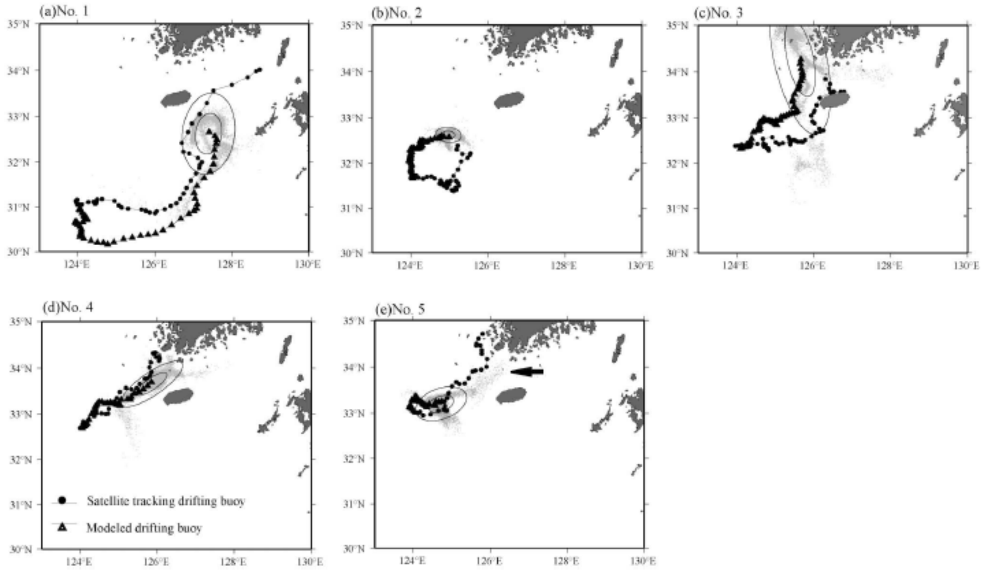


Figure 2.5. Trajectories of the observed drifters (solid lines with circles) and daily averaged position of modeled particles (solid lines with triangles) during 2003 (Kako et al., 2010a)

However, the difference between the modeled particles and observed drifters was remarkable in 2007 experiments, probably due to the wind-induced leeway drift. Leeway drift is the motion to leeward of an object floating on water caused by the component of the wind vector that is perpendicular to the object's forward motion. Kako et al. (2010a) used the ratio of the distance between the daily averaged position of modeled particles and sigma-ellipse to the distance between daily averaged position of modeled particles and observed drifters (Fig. 2.6). They compared the wind speeds among three experiments years and concluded that the most plausible cause responsible to the discrepancies between modeled and observed trajectories is the slip velocity induced by intense winds. Thus, it was suggested that the additional algorithm incorporating the leeway drift into particle motion does not successfully reproduce drifter motion. They also mentioned that using a constant ratio of drag coefficient is not always a reasonable assumption and thus one needs to consider the drag coefficient that changed drastically at the Reynolds number of O (10^5). For the future study, the authors proposed well-controlled laboratory experiments for an accurate estimation of the ratio between drag coefficients of air/water.

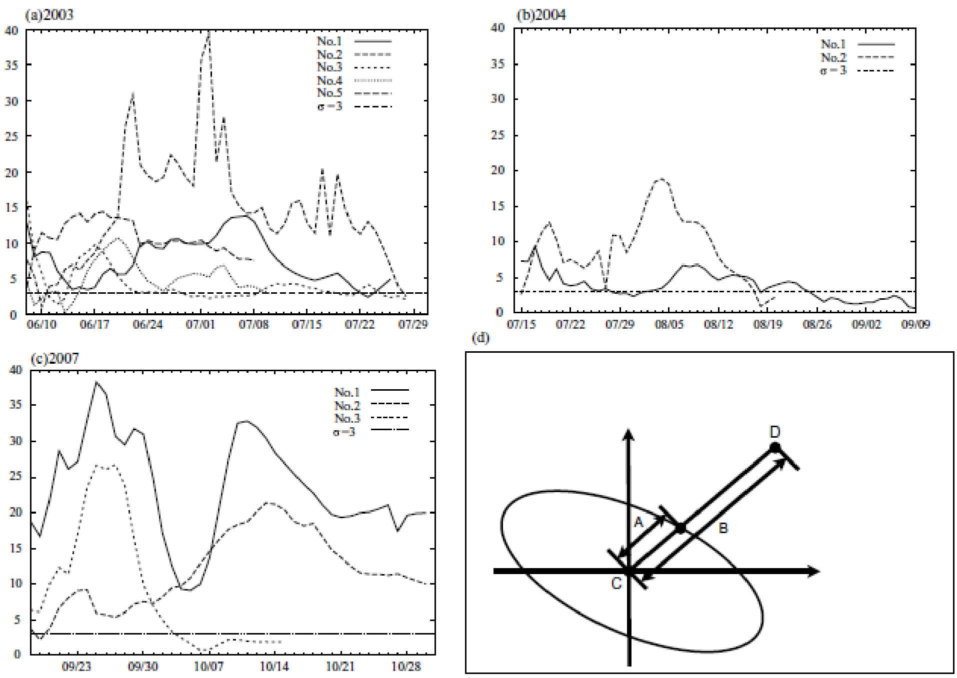


Figure 2.6. Temporal variation of the distance ratio between 'A' and 'B' defined in the panel (d) in (a) 2003, (b) 2004 and (c) 2007. (Kako et al., 2010a)

In the same area, Kako et al. (2010b) applied a similar approach which is documented in Kako et al. (2010a) to examine the number of plastic-bottle caps found in the Hassakubana beach, Japan. More specifically, by using a two-way particle tracking model combined with an inverse calculation, the origins of marine litter shored a certain area in Japan, in the vicinity of Goto Islands, was investigated while comparing with an actual beach survey data (Kako et al., 2010b) as shown in Figure 2.7. The bar heights show the number of plastic bottle caps that were originated from the sources. The colors represent the month when the caps were released from each source. The results show that the number of the caps originated from China was not so different from those originated from Korea and Japan and the seasonality in the fate of the plastic bottle caps reaching the Hassakubana beach either.

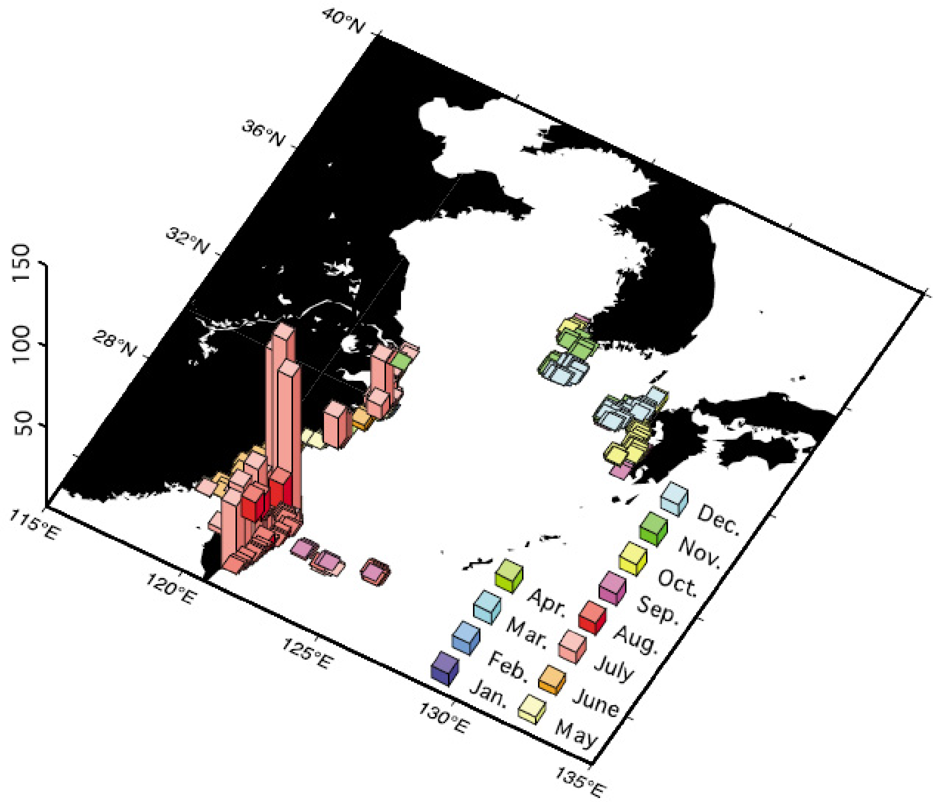


Figure 2.7. Origins of plastic-bottle caps found at a Japanese island using the inverse method. (Kako et al, 2010b)

The temporal variability of the drifting-object amount was investigated on a beach located in the west of Japan (Kako et al., 2010b). They also implemented two-way particle tracking model experiments using simulated ocean currents and leeway drift estimated from QuikSCAT/Seawinds wind data. In addition, the authors applied an inverse method with a Lagrange multiplier using a particle tracking modeling and beach-survey results. They compared the number of the plastic-bottle caps found in actual beach surveys with that computed using a particle tracking method. The results showed that the sources of the disposable-lighter identified in the two-way particle tracking experiments are consistent with those suggested by the phone numbers printed on the lighter's surface in the beach surveys. The seasonality of the plastic bottle caps reaching the beach in the model results is also consistent with the beach survey results, which also confirmed the accuracy of the model application.

Although the study area is limited by the domain of the ocean circulation, the method could be applied to other area once an ocean model becomes available.

A similar approach was applied in Kako et al. (2011) attempting to establish a system for simulating the quantity of litter reaching a beach using an ocean circulation model, a two-way particle tracking model to find litter sources. The model domain in Kako et al. (2011) also covers the Yellow Sea and East China Sea region. Also, they applied similar inverse method to estimate litter outflows at each source (Kako et al., 2011). They showed the hindcast/forecast of the quantity of beach litter in Goto Islands, Japan. In this study, they used twelve actual beach survey results, and satellite and forecasted wind data were also used (Fig. 2.8).

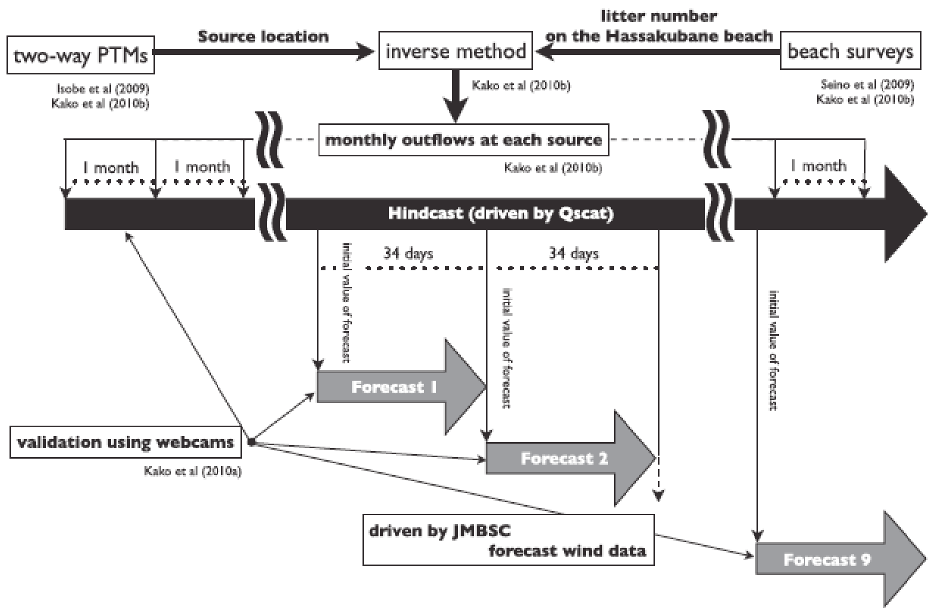


Figure 2.8. Flowchart of the hindcast and forecast computations used in Kako et al (2011) study (Kako et al. 2011)

The results of the study showed that the forward in-time model using the surface currents derived from the ocean circulation model and satellite-derived/forecasted wind data was able to reproduce the quantity of the beach litter (Kako et al., 2011). Their results suggested that the time-series of the simulated quantity of the beach litter was consistent with the quantity of the beach litter that was estimated from webcam images set up on the beach (Fig. 2.9).

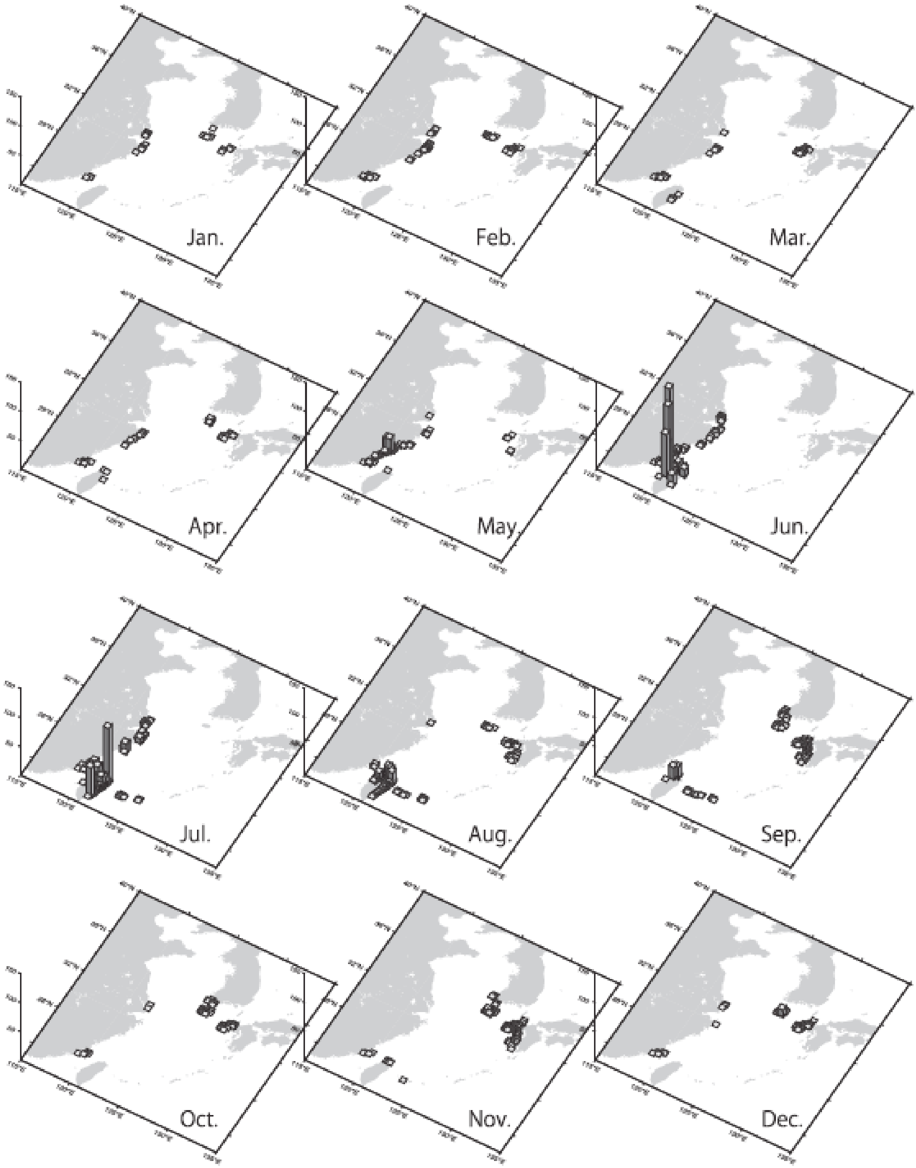


Figure 2.9. Plastic-bottle cap outflows computed using inverse methods (Kako et al, 2011.)

In the North Pacific Ocean, there is an area where floating plastic debris accumulates. This is called the great garbage patch (Kubota, 1994). Contrary to what the name seems to imply, the patch is consisted of small pieces barely visible to human eyes. (It does not mean that the plastic debris is harmless.) Similar patches of floating plastic debris are in other major oceans. These patches are made due to converging effect of ocean currents as a simulation conducted by Dohan and Maximenko (2010) as shown in Figure 2.10. For this, simulation of ocean currents measured from satellite sensors has been used.

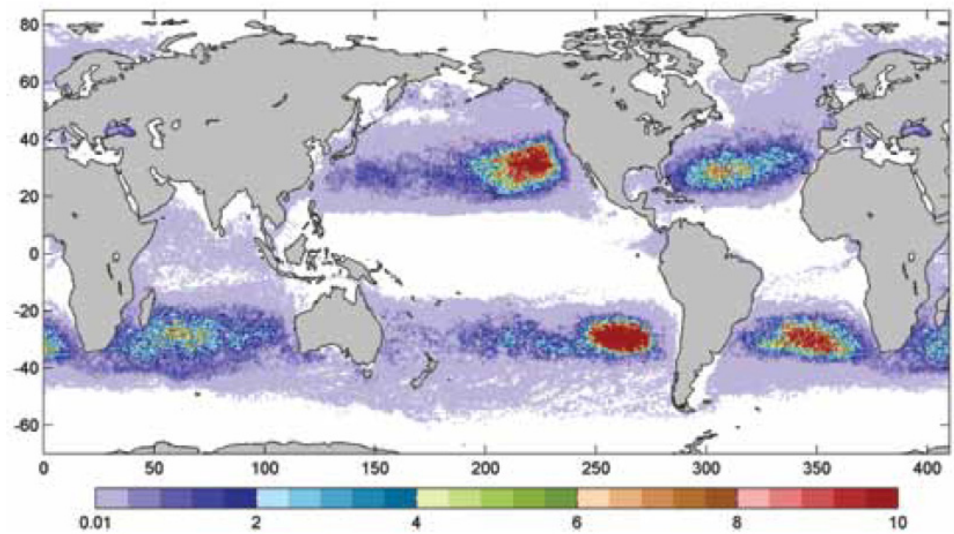
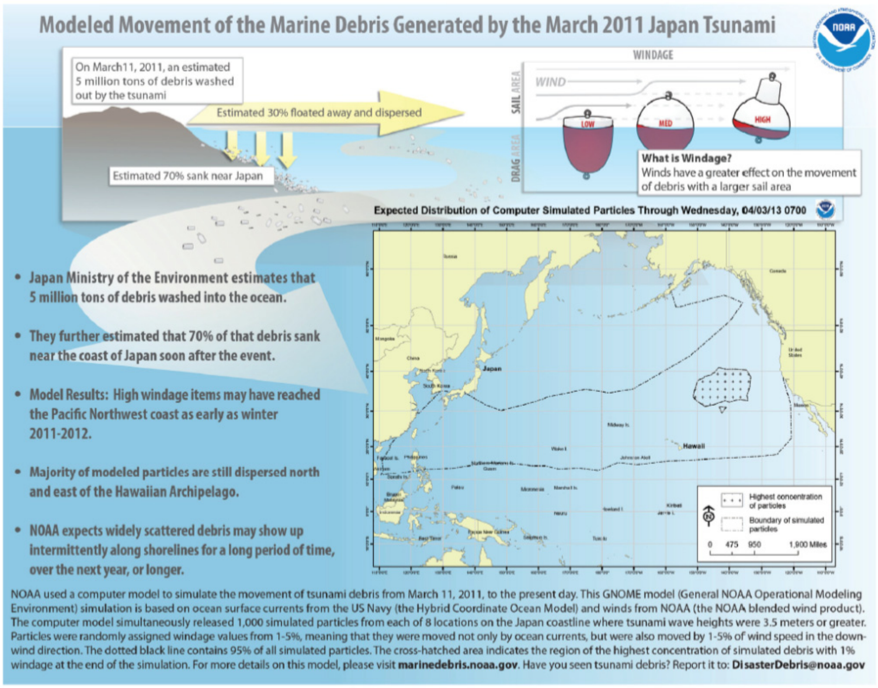


Figure 2.10. Convergence zones of floating drifters. (Dohan and Maximenko, 2010)

A tsunami struck Fukushima, Japan on March 11, 2011. It imposed 5 million tons of diverse types of debris into the North Pacific. The General NOAA Operational Modeling Environment (GNOME model) was used to simulate the movement of the tsunami debris, based on the ocean surface currents (HYCOM) and winds. It was estimated that about 70 % will be sunk near Japan while the remaining 30% will be floated away and dispersed (NOAA, Severe Marine Debris Event Report: Japan Tsunami Marine Debris) (Figure 2.11). It was possible that the debris would be drifted westward due to the subtropical gyre toward the west coast of US. To cope with the debris, a modeling was conducted using ocean currents and wind data. In the figure below, the potential area with the highest concentration of debris as of April 2013 is shown.



Modeled movement of the debris generated by the March 2011 Japan tsunami. The model gives NOAA an understanding of where debris from the tsunami may be located today, because it incorporates how winds and ocean currents since the event may have moved items through the Pacific Ocean. This model is a snapshot from April 2013, of where debris may be now, but it does not predict when debris will reach U.S. shores in the future. It's a "hindcast," rather than a "forecast."

Figure 2.11. Diagram for marine debris modeling. (NOAA 2013)

In Figure 2.12, another modeling result is shown (Laurent et al., 2013). In the figure, the time for marine litter to reach a certain location from the original source Fukushima, Japan is shown. The shape of the travel time map is about the same as the ocean circulation pattern in the North Pacific, the subtropical gyre. The movements of the debris crossing the gyre boundary is limited and the debris remains within the gyre.

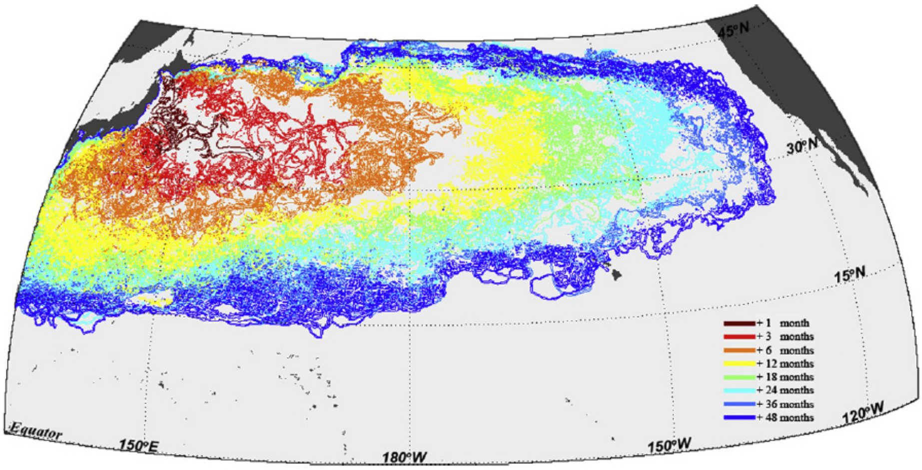


Figure 2.12. Time for tsunami debris to reach a certain location from the origin Fukushima, Japan. (Laurent et al., 2013)

In fact, particle tracking modeling could be applied for many different objects in the oceans. One of such examples is floating algae. Green algae patches crossing the sea were observed from a satellite and those were traced by sequential satellite images (Son et al., 2012). Son et al. (2015) conducted Lagrangian particle tracking experiments to understand the pathway of the floating green algae patches utilizing ROMS-derived ocean currents and KWRF wind in the Yellow Sea and East China Sea region. The numerical simulation results in Figure 2.13 shows that the floating green algae were significantly controlled by both ocean currents and enhanced winds especially during the passage of typhoon (Son et al., 2015). The general transport pattern shows that those green macroalgae were originated from Chinese coasts and transported toward west or northwest, some of which ends up in Korean coasts or others keep moving onto Korean strait via the Tsushima currents. The simulation results were consistent with the satellite-derived observation data. Although this was not a direct application of satellite and numerical modeling data onto marine litter, this study shows the potential capability of such approach in studying the transport and fate of marine litter.

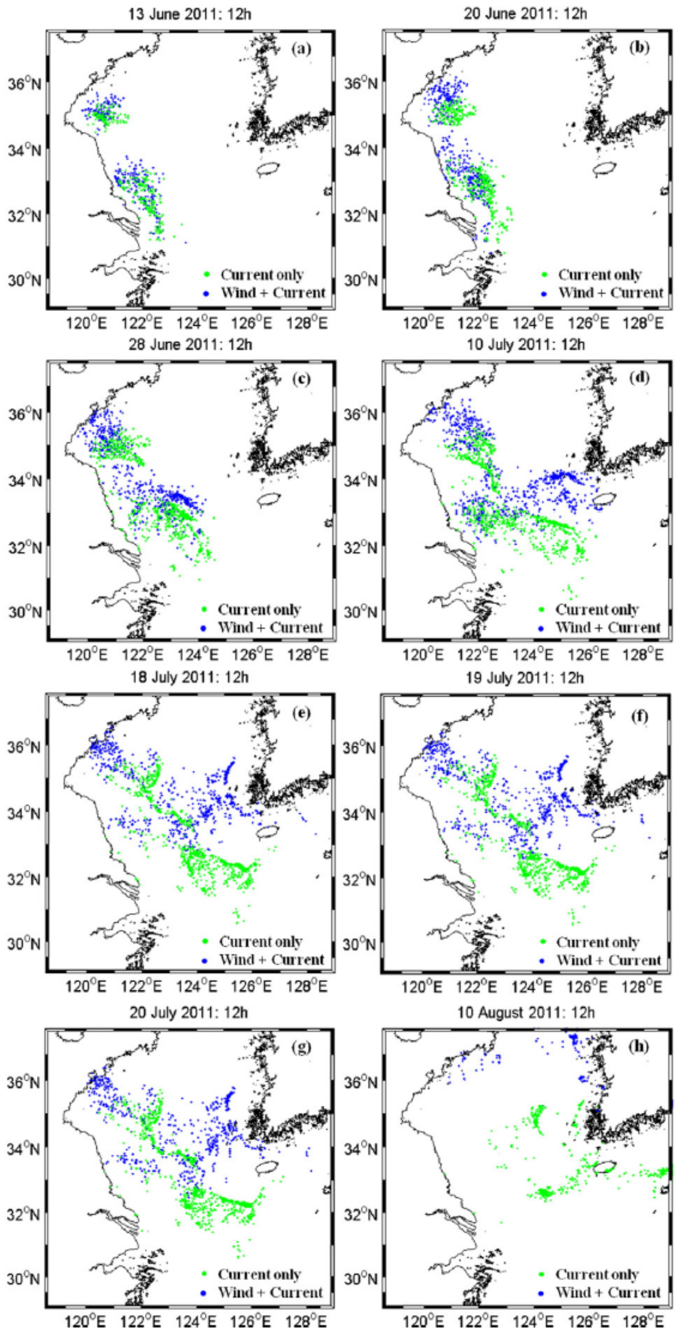


Figure 2.13. Locations of particles from the Lagrangian particle-tracking experiments (Son et al., 2015). Green dots represent particles transported only by currents while blue dots represent transportation by wind and currents.

The quantity and size distribution of small plastics were investigated in the Seto Inland Sea, Japan (Isobe et al., 2014). A numerical particle-tracking model was used to interpret the distributions of small plastic fragments and the possible transport processes in coastal waters. Their numerical model, presented in Figure 2.14, successfully reproduced the near-shore trapping of mesoplastics, suggesting that mesoplastics are selectively conveyed onshore by a combination of Stokes drift and terminal velocity, dependent on fragment sizes.

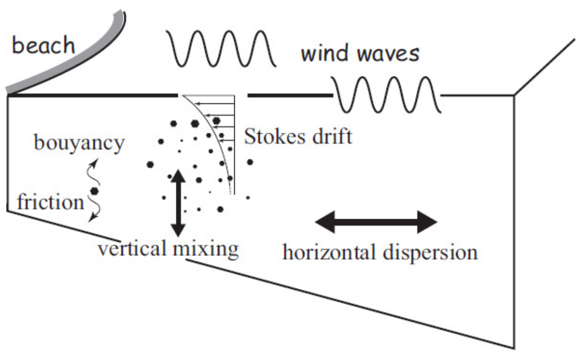
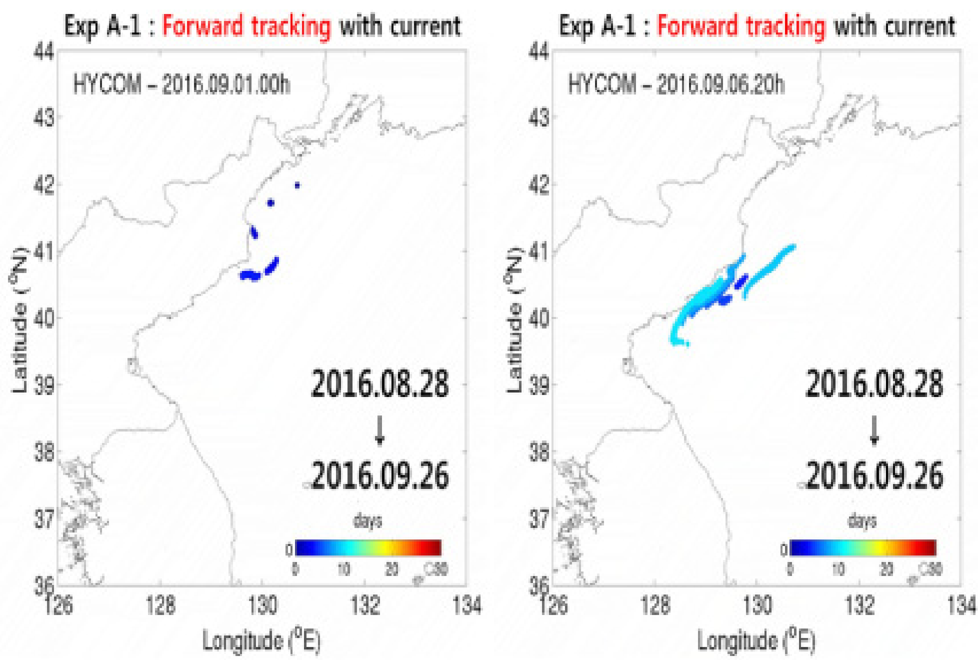


Figure 2.14. Schematic view of the selective onshore transport of mesoplastics (Isobe et al., 2014)

Several typhoons pass through the NOWPAP region every summer and fall with a large amount of rainfall and strong wind. Typhoon induced flooding introduce large amount and various type of debris into the ocean through rivers and streams. The wind from a typhoon could be conducive to the unseen drifts of marine debris. Large debris such as woods could be hazardous to maritime activities. The debris could accumulate in a coastal area within a short time causing various concerns or damages. One example is the flooding caused by the Typhoon Lionrock in August 2016 which passed through the middle of the NOWPAP Sea area. After passing Japan, the typhoon landed near the border between Russia and North Korea. The river between Russia and North Korea was flooded, and a large amount of debris was discharged into the sea. Weeks after the flooding, a large amount of debris was reported to be present along the east coast of Korea.

A forward tracking numerical modeling experiment (Figure 2.15) was conducted to simulate the movement of debris by using global HYCOM in the area of Russia and North Korea (Park et. al., in preparation). Details of HYCOM currents data that were used to simulate the particle transport are described in the next chapter. The results show that the numerical results are consistent with the results of the satellite-derived observation and some debris was found in the beaches of South Korea. This study shows the applicability of the results of the current high resolution global ocean model for a marginal sea.

In Figure 2.15, one can see the snapshots of particle distribution that were released from the river between North Korea and Russia. Debris discharged from the river moved southward along the coast line mainly due to the North Korea current for the first 10 days or so (Aug 28 - Sep 06, 2016). During the next 10 days, some of the particles kept moving toward south along the coastline while the other group of the particles was transported in northeastward direction. About a month after the particles were released, they reached the South Korean coastlines. Some of the debris moved in offshore direction which could become hazardous to vessels and fishing net.



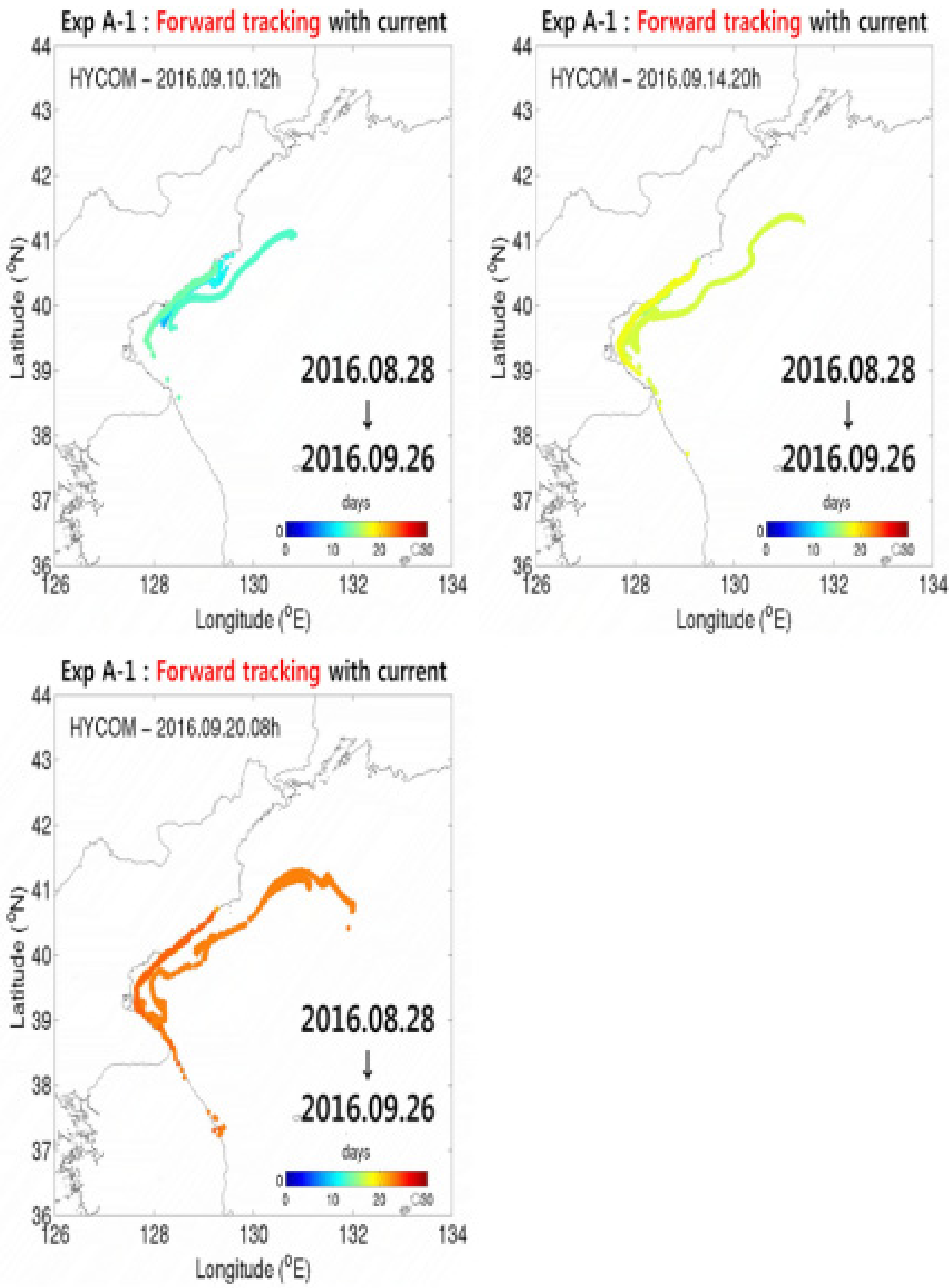


Figure 2.15 Particle distribution map from the forward tracking modeling experiments. Each panel shows the snapshots taken on Sep. 1st, Sep 6th, Sep 10th, Sep 14th, and Sep 26th.

One of the benefits of using this global model is that one could test hypothesis and then if necessary a fine-tuned experiment can be conducted using current data that represents the area better. Although the local models can better reproduce currents for the area of interest, they cannot be applicable beyond the domain. On the other hand, these global models may lack details but is able to show an overall connectivity.

Chapter 3. Factors affecting floating marine litters

3.1. Major factors

The primary factor governing the trajectories of marine litter is the ocean currents, and the secondary one is surface wind. In order to assess the ocean currents and wind, a substantial amount of observational, theoretical and numerical studies has been conducted. From the maps of ocean currents one can roughly infer the fate of marine litter. To quantify the fate, gridded numerical values of currents and wind, which have become readily available during the past decade, are necessary. In this section, the currents and wind systems around the NOWPAP region are discussed first and then available numerical model outputs are introduced.

The most prominent ocean current in the northwestern Pacific Ocean is the Kuroshio Current, moving clockwise along the western perimeter of the ocean, from the Philippines to Japan (Fig. 3.1). This current carries warm subtropical waters to the mid-latitudes and plays an important role in shaping the climate of the area. At about 34º N, Kuroshio turns eastward to become the Kuroshio Extension, flowing east towards the North America. There is another strong current, the Oyashio, flowing from the north along the perimeter. At about 40º N, this current also turns to become the Oyashio Extension flowing to the east. The Kuroshio and Oyashio currents are responsible for the eastward drift of debris from the Fukushima earthquake.

China and Korea are not influenced by the Kuroshio Current directly, but the currents found around here originate from the Kuroshio, at least in part (Isobe, 2008; Park et al., 2013). A part of the Kuroshio flows toward the South China Sea through the Luzon Strait between the Philippines and island of Taiwan to feed the Taiwan Warm Current, which passes through the Taiwan Strait toward the East China Sea. Upon joining with a current branching from the Kuroshio, southwest of Japan, the Taiwan Warm Current becomes the Tsushima Warm Current, which flows into the sea surrounded by Korea, Japan, and Russia through the strait between Korea and Japan. Upon entering the sea, this current bifurcates into two main branches. One of the branches flows northward following the east coast of Korea and then turns east to flow toward Japan. The other branch follows the west coast of Japan. Near the Tsugaru Strait, this branch joins with the branch following the east coast of Korea. Most of the combined current then leaves the sea through the Tsugaru Strait to the

North Pacific. The remaining part continues toward the northern part of the sea. Along the Russian coast and North Korean coast, southward currents, Primorye Cold Current (PCC) and North Korea Warm Current (NKCC), are found.

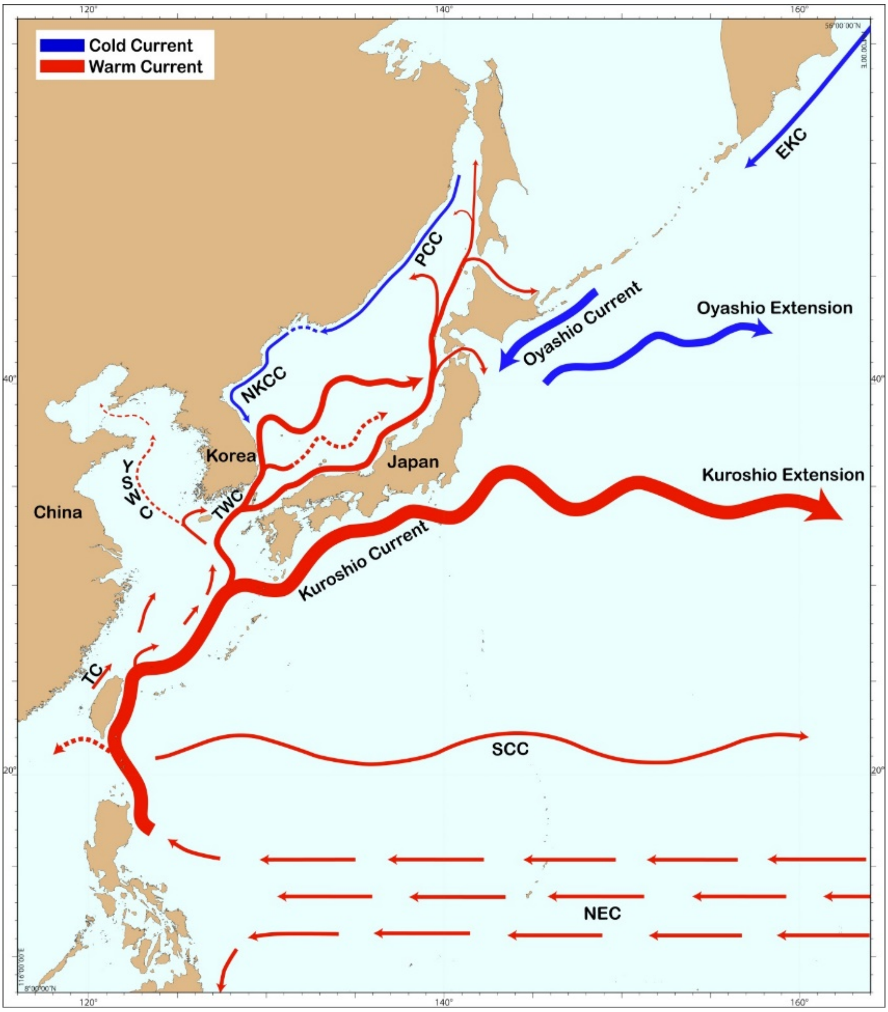


Figure 3.1 Map of the major ocean currents over the northwestern Pacific. Here TC stands for the Taiwan Warm Current, TWC – Tsushima Warm Current, YSWC – Yellow Sea Warm Current, NKCC – North Korea Warm Current, PCC – Primorye Cold Current, EKC – East Kamchatka Current, NEC – North Equatorial Counter Current, and SCC – Subtropical Counter Current. This map is adopted from those provided by the Korea Hydrographic and Oceanographic Agency (KHOA).

In the sea, surrounded by China and Korea, ocean currents show prominent seasonality (Fig. 3.2). The sea is very shallow and is affected by the monsoon wind, which reverses depending on seasons as shown in Figure 3.3. In winter, the northwesterly wind from the Asian continent prevails, while in summer, the southeasterly wind prevails (Fig. 3.3). This large change in the wind is conducive to the seasonality of the ocean currents, as described below. In winter, a warm current, the Yellow Sea Warm Current (YSWC), branches from the Kuroshio Current and flows northward along the central axis of the Yellow Sea. To the east, the Korean Coastal Current (KCC), a current moving southward along the west coast of Korea, is found. To the west, the Chinese Coastal Current, a current moving southward along the east coast of China, is found. The Yangtze River Discharge Flow (YDF) moves southwestward along the Chinese coast. In summer, the YSWC disappears, and the KCC reverses, flowing northward along the west coast of Korea. The YDF, which is about 5 to 6 times stronger in summer than in winter, flows toward the Korea Strait and the NOWPAP region.

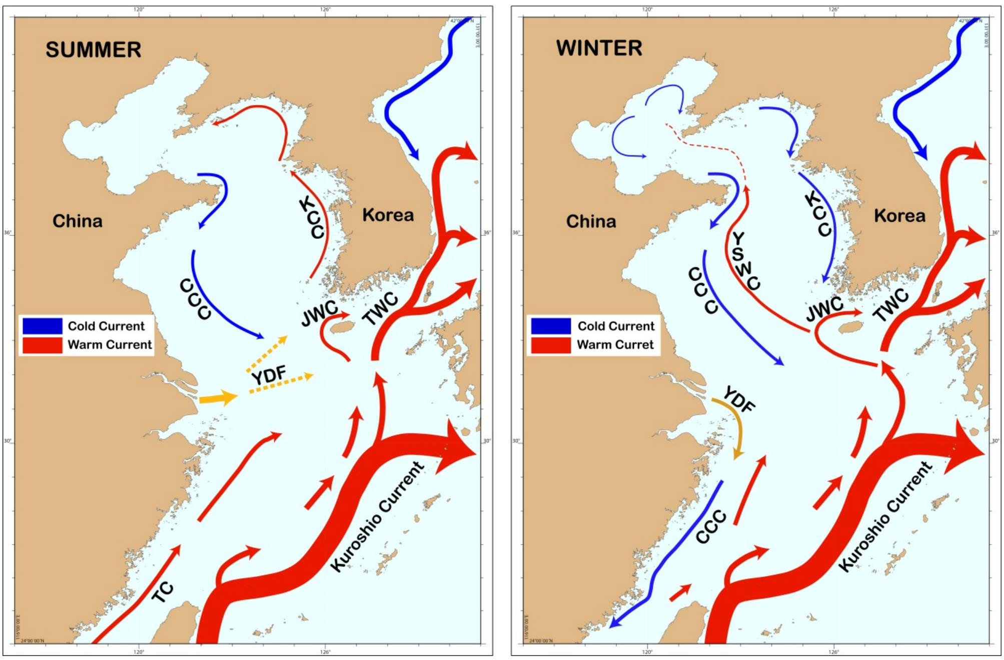


Figure 3.2 Ocean Currents in the Yellow Sea and East China Sea in summer (left) and winter (right). Here KCC stands for Korea Coastal Current, CCC – Chinese Coastal Current, JWC – Jeju Warm Current, and YDF – Yangtze River Discharge Flow. This map is adopted from those provided by KHOA.

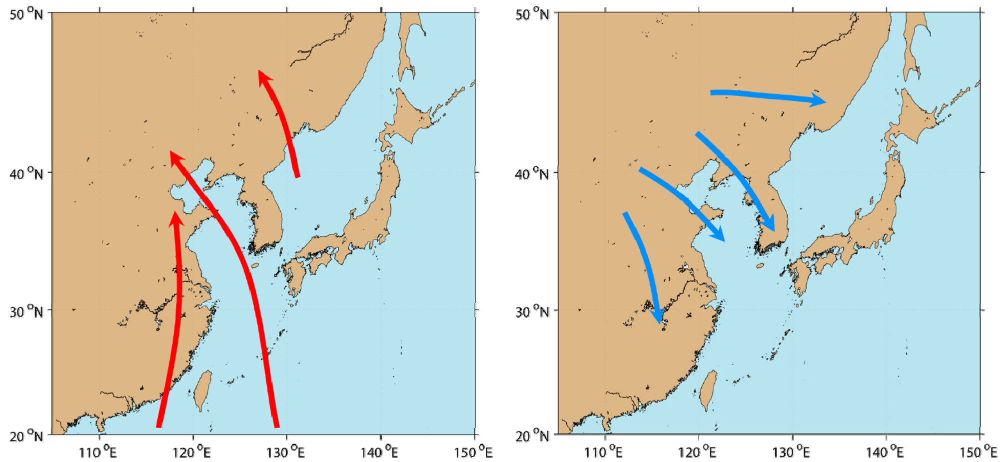


Figure 3.3 Monsoon pattern during (a) summer and (b) winter

3.2. Existing data in the NOWPAP region

Ocean current data

Numerical modeling has become more common for the past decade and there are several ocean current data products one can utilize for marine litter tracking. Some data products are open to the general public while some are not. The characteristics of marine litter tracking are determined by the data products utilized. For example, if a regional data covering the NOWPAP region is utilized, one could investigate the movement of marine litter from one NOWPAP member state to another. If we are to investigate the influence of the NOWPAP member states as one region to the North Pacific, a model of a wider domain is necessary. Or if a detailed movement of marine litter within a limited area is of interest, a high resolution model should be adopted.

There are several national institutes and research groups that have produced ocean current data in the NOWPAP region. For example, in China, the National Marine Environmental Forecasting Center operates ocean circulation models tuned for different domains ranging from the entire North Pacific to local area around China. In Japan, JAMSTEC is running Japan Coastal Ocean Predictability Experiment with which ocean current data of 1/12 degree horizontal resolution data for the North Pacific including the NOWPAP region are produced (Miyazawa et al., 2017). In Korea, the Korea Institute of Ocean Science Technology (KIOST) has an ocean prediction system of 1/24 degree horizontal resolution for the northwestern Pacific (Park et al., 2015). Some of the aforementioned data sets are readily available.

There are global data sets open to the public through the Internet. One is HYbrid Coordinate Ocean Model (HYCOM) provided by the HYCOM consortium (https://hycom.org/). An example snapshot of the surface current from HYCOM is shown in Figure 3.4. The HYCOM data covers the entire global area, and we can just select and download the data covering the NOWPAP region. In general, archived data for hindcasting are available, along with 14-days forecast from today. Temporal resolution is 1 day and spatial resolution is 1/12 degree which is close to about 8 km in mid-latitude area like the NOWPAP region. However, among the 40 layers of 3-d data available, only surface currents are used for marine debris modeling. Data format is saved in a common data format (i.e., NetCDF).

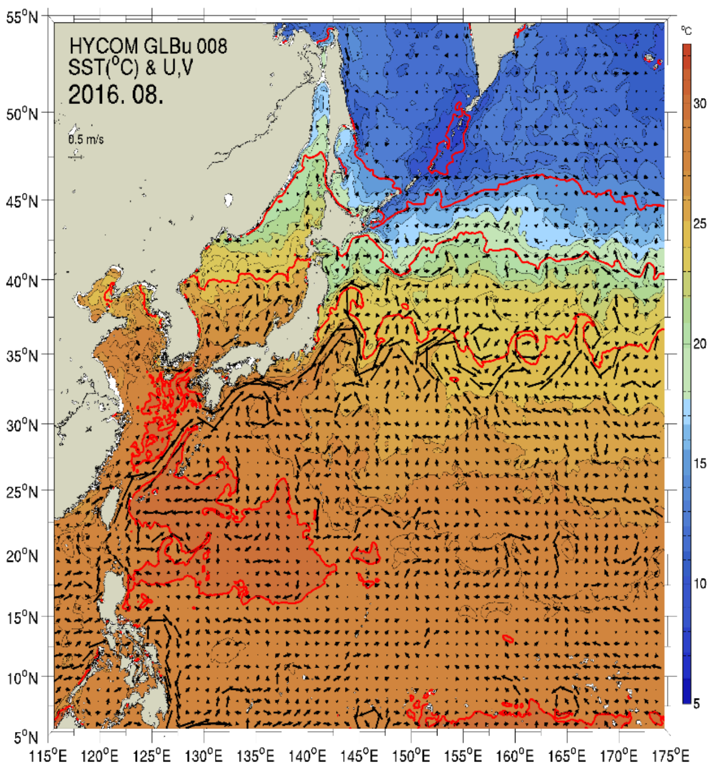


Figure 3.4 Ocean current in the NOWPAP region from HYCOM. The vectors show the direction and magnitude of currents, and color contour represents the sea surface temperature.

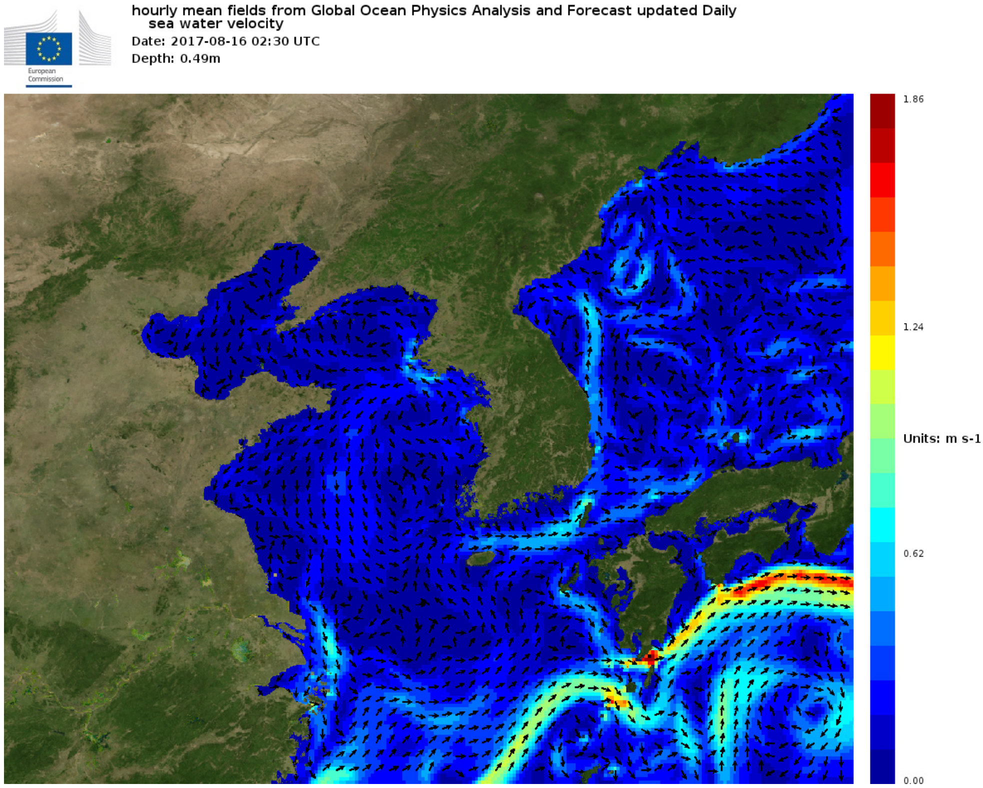


Figure 3.5 Ocean current in the NOWPAP region from http://marine.copernicus.eu

Another one is MYOCN by Copernicus Marine environment monitoring service (http://marine.copernicus.eu/) as shown in Figure 3.5. The spatial resolution of both models is about 8 km and may not be high enough to investigate detail movement of marine litter, but good enough to study the connectivity between the NOWPAP member states. The currents from the model, of course, should be validated before applying to the tracking of marine debris. Seo et al. (in press) compared the HYCOM outputs with the observed data, and reported that the model is able to reproduce the oceanographic condition of the strait between Korea and Japan and the sea surrounded by Korea, Japan and Russia.

Wind data

The metrological agencies in each NOWPAP member state make weather predication and the information could be used in modeling the fate of marine litter. The individual agency would produce data sets that are optimized for the state it belongs and the neighboring states, but the data sets are not always open to the general public. Similar to the global ocean current data sets, there are global wind data sets one could download from the Internet. One popular website is NCEP and another one is ECMWF. They provide both forecast and reanalysis in which observation data optimally assimilates into a numerical model.

Particle Tracking Modeling

In order to predict the transport and fate of marine litter, the Lagrangian particle tracking modeling can be applied with the ocean currents and wind data. Global and basin-scale ocean currents model could suggest regions of convergence of marine litter. Higher-resolution nested model can also be useful to simulate local-scale patterns of marine litter accumulation. Further development of the ocean currents model, i.e., one being implemented with data assimilation or large-eddy simulation technique, can warrant higher levels of accuracy in particle tracking models.

Furthermore, there are several key factors that need to be considered in particle tracking models. For instance, the windage impact is quite critical but yet difficult to be parameterized simply. NOAA (2013)'s Japan Tsunami debris report and Yoon et al. (2009) show that the results of particle tracking model can be dramatically different depending on how windage effects are incorporated in the simulation of marine litter. When parameterizing the windage on marine litter transport simulation, it is important to count on the influences of buoyancy ratio, litter shape, leeway drift, and stokes drift (e.g., Yoon et al., 2009; Kako et al., 2010a, b; NOAA, 2013; Isobe et al., 2014).

Chapter 4. Conclusions and recommendations

In this report, the state-of-the-art techniques applied in floating marine litter prediction has been reviewed. Important factors controlling the transport and fate of marine litter, for instance ocean currents, wind, and parameters used in the modeling, were discussed. Based on the review of the current techniques, here are some suggestions that could be considered for future development:

Integrated modeling approach for the NOWPAP region

In short, each model has pros and cons and the comparison results confirm that there cannot be a single model which can simulate the transport and fate of marine litter for the entire NOWPAP region. By far, each NOWPAP member state has developed numerical models for wind and ocean currents, and some states also implemented litter-tracking models. For instance, wind and currents models for the area of Yellow Sea and East China Sea are found in Yoon et al. (2010), Kako et al. (2010a, 2010b, 2011), and Son et al. (2015), and those for the NOWPAP region are used in Yoon et al. (2010) and Seo et al. (in press). However, there are no integrated efforts to develop numerical models to cover the entire NOWPAP region, covering from the South China Sea through East China Sea, Yellow Sea, and the NOWPAP region to the northwest Pacific region. Marine litter transport, similar to other geophysical phenomena, is not limited to geopolitical bounds. Thus, there must be collaborative efforts to solve the marine litter issue.

Specific attention on the modeling of microplastics

Focus on microplastic litter research has been emerging recently not only in the NOWPAP region but also globally. Primary microplastics are originally created to be of small scale or microscopic size, while secondary plastics are pieces of larger plastics that have been broken down into small pieces (Cole et al., 2011; Hardesty et al., 2017). One of the marine sources for such secondary microplastic is the degraded material from Styrofoam buoy used for fishing and aqua farms. The NOWPAP region is known for its busy fishing and aqua farm activities, which results in high chance of exposure to these secondary microplastics. Microplastics can be found in beach sediment, sea-surface areas, mid-ocean areas, and even in benthic areas. They have recently been a concern for the environment, marine life health and safety, and also human health and safety. Numerical models simulating macro size of litter (i.e., larger than order of centimeters) were relatively well studied.

However, models incorporating micro size (order of millimeter) have not been sufficiently conducted yet. There is a necessity to develop numerical models simulating the transport and fate of microplastics in the ocean, especially in the NOWPAP region.

Further development in the estimation of leeway drift

Kako et al. (2010a) proved that the leeway drift is not simply proportional to wind speeds. It is due to the importance of leeway drifts in determining the trajectories of observed drifters. In order to incorporate the leeway drift into the particle tracking algorithm, Kako et al. (2010a) utilized the Richardson (1997)'s relationship between the wind speed and leeway drift, where a coefficient 'r' is employed as the ratio of drag coefficient between air and water. In most cases, this ratio is assumed to be constant, but it might be unreasonable to use a constant ratio under intensely windy conditions. To overcome such limited application of drag coefficient ratio between air/water, it was proposed to conduct well-controlled laboratory experiments for an accurate estimate of drag coefficients of air and water and the ratio of those (Kako et al., 2010a).

References

Cole, Matthew, Pennie Lindeque, Claudia Halsband, and Tamara S. Galloway., 2011, Microplastics as contaminants in the marine environment: A Review." *Marine Pollution Bulletin* 62: 2588-597.

Dohan, K. and N. Maximenko. 2010. Monitoring ocean currents with satellite sensors. *Oceanography* 23(4): 94-103, doi:10.5670/oceanog.2010.08.

Hardesty BD, Harari J, Isobe A, Lebreton L, Maximenko N, Potemra J, van Sebille E, Vethaak AD and Wilcox C (2017) Using Numerical Model Simulations to Improve the Understanding of Micro-plastic Distribution and Pathways in the Marine Environment. Front. Mar. Sci. 4:30. doi: 10.3389/fmars.2017.00030

Isobe, A., Kenta Kubo, Yuka Tamura, Shin'ichio Kako, Etsuko Nakashima, Naoki Fujii, Selective transport of microplastics and mesoplastics by drifting in coastal waters. Marine Pollution Bulletin 89 (2014) 324-330.

Kako, S., A. Isobe, S. Yoshioka, P, Chang, T. Matsuno, S.H. Kim, and J.S. Lee, 2010a, Technical Issues in Modeling Surface-Drifter Behavior on the East China Sea Shelf, *Journal of Oceanography*, Vol. 66, pp. 161-174.

Kako, Shin'ichiro, Atsuhiko Isobe, Satoquo Seino, Azusa Kojima, 2010b, Inverse Estimation of Drifting-Object Outflows Using Actual Observation Data, *Journal of Oceanography*, Vol. 66, pp. 291-297.

Kako, Shin'ichiro, Atsuhiko Isobe, Shinya Magome, Hirofumi Hinata, Satoquo Seino, Azusa Kojima, 2011, Establishment of numerical beach-litter hindcast/forecast models: An application to Goto Islands, Japan, Marine Pollution Bulletin 62 (2011) 293-302.

Kubota, M., 1994, A Mechanism for the Accumulation of Floating Marine Debris North of Hawaii. Journal of Physical Oceanography, v. 24, p. 1059-1064.

Laurent C.-M. Lebreton a, Jose C. Borrero, 2013, Modeling the transport and accumulation floating debris generated by the 11 March 2011 Tohoku tsunami, Marine Pollution Bulletin 66: 53-58.

Miyazawa, Y., Varlamov, S.M., Miyama, T. et al. Ocean Dynamics (2017) 67: 713. doi:10.1007/s10236-017-1056-1

NOAA Severe Marine Debris Event Report: Japan Tsunami Marine Debris, Overview and Update to Congress | August 2013.

National Oceanic and Atmospheric Administration Marine Debris Program, 2016, Report on Modeling Oceanic Transport of Floating Marine Debris. Silver Spring, MD. 21 pp.

Park, KS., Heo, KY., Jun, K. et al., 2015, Development of the Operational Oceanographic System of Korea, Ocean Sci. J. v. 50, https://doi.org/10.1007/s12601-015-0033-1

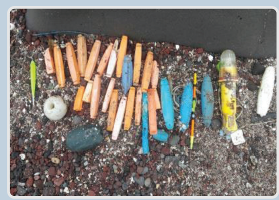
Richardson, P. L. 1997, Drifting in the wind: leeway error in ship drift data. *Deep-Sea Res.*, 44(11), 1878-1903.

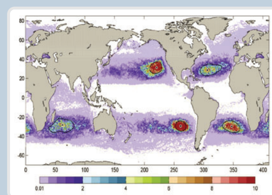
Son, Y.B., Min, J.E., & Ryu, J.H. (2012). Detecting massive green algae (Ulva prolifera) blooms in the Yellow Sea and East China Sea using Geostationary Ocean Color Imager (GOCI). Ocean Science Journal, 47(3), 359-375.

Son, Y.B., B.J. Choi, Y.H. Kim, and Y.G. Park, Tracing floating green algae blooms in the Yellow Sea and the East China Sea using GOCI satellite data and Lagrangian transport simulations. Remote Sensing of Environment, v. 156, p. 21-33.

Thompson, R.C., Y. Olsen, R.P. Mitchell, A. Davis, S.J. Rowland, A.W.G, John, D. McGonigle, and A.E. Russell, 2004, Lost at Sea: Where is All the Plastic? Science, v. 304, p. 838.

Yoon, Jong-Hwan, Shiro Kawano, Shuzo Igawa, 2009, Modeling of marine litter drift and beaching in the Japan Sea, Marine Pollution Bulletin, v. 60, 448-463





NOWPAP MERRAC

Northwest Pacific Action Plan
Marine Environmental Emergency Preparedness and Response
Regional Activity Centre

UNEP IMO

1312-32, Yuseong-daero, Yuseong-gu, Daejeon 34103, Republic of Korea
Korea Research Institute of Ships & Ocean Engineering (KRISO)
Tel: (+82-42) 866-3638, FAX: (+82-42) 866-3630
E-mail: nowpap@kriso.re.kr
Website: http://merrac.nowpap.org

93500
9 788993 604399
ISBN 978-89-93604-39-9