Inverse estimation of marine-debris outflows using webcam observation data

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Introduction

There are huge amount of marine debris washed ashore on the beach.

Sample photograph of marine-debris taken by webcam on the beaches of Tobishima Island (Kataoka et al., 2012)

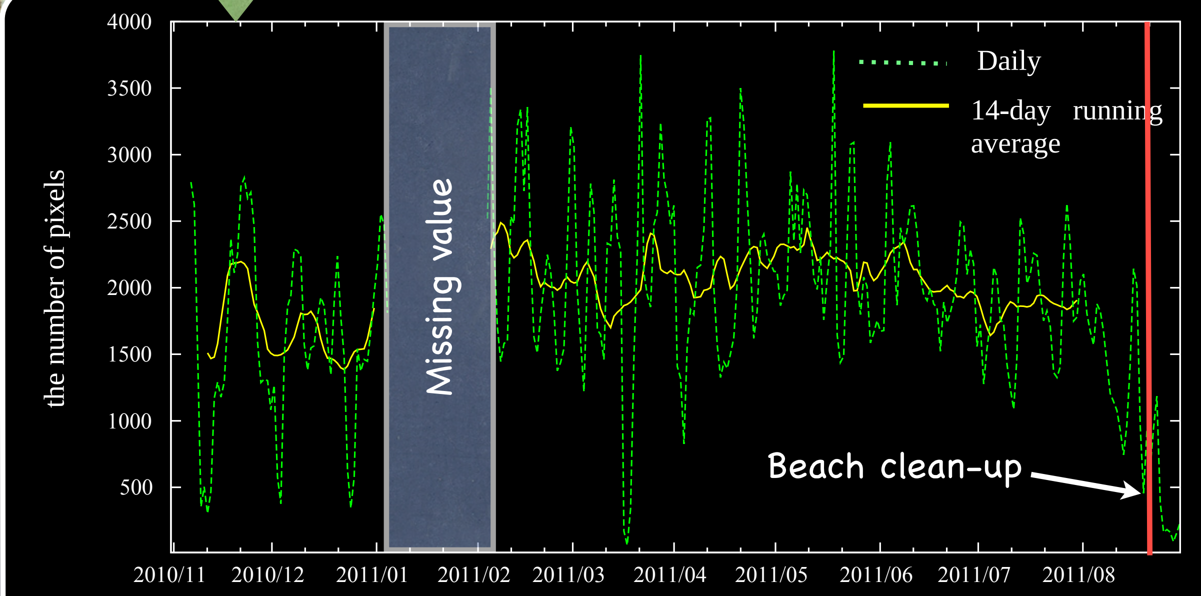
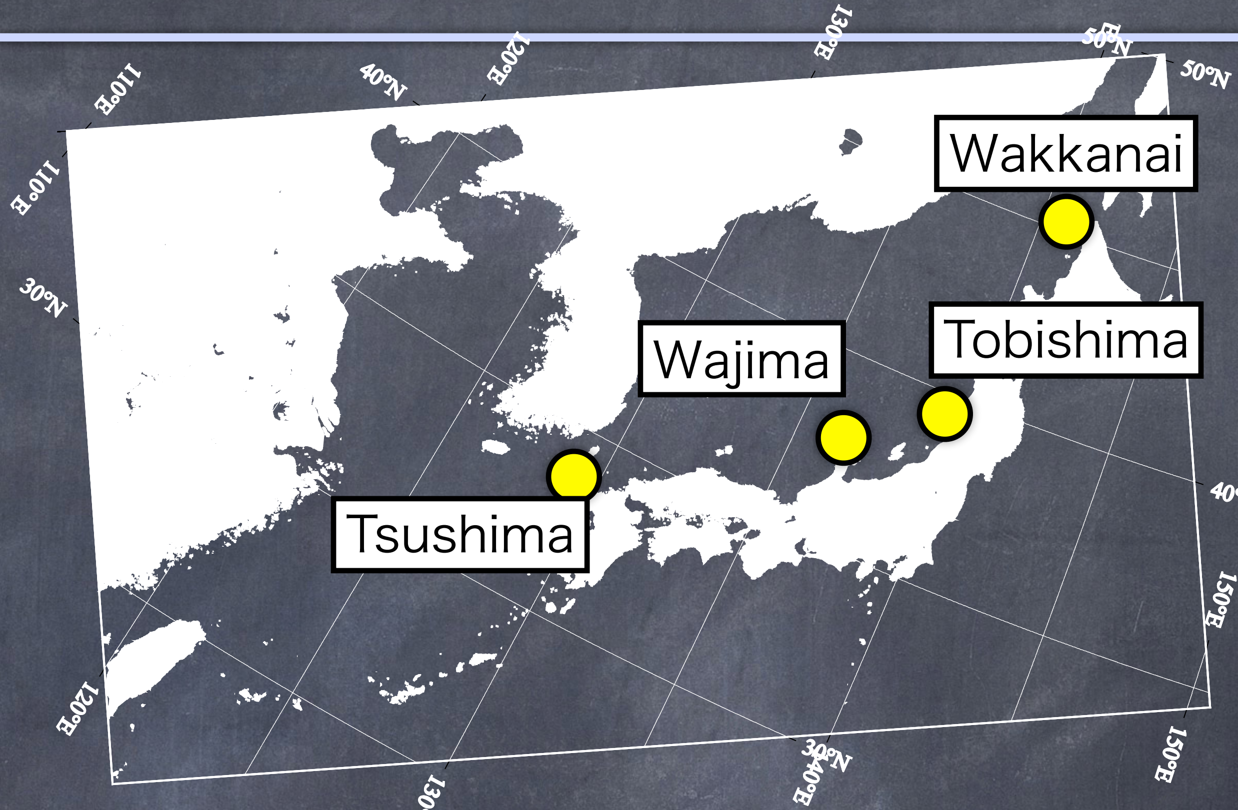


Figure. Time series of area covered by beach litter. Green line denotes the daily mean. Yellow line denotes the time series smoothed by 14-day running average.

Introduction



The purpose of present study is to provide a procedure to convert this imagination into identification.

- Two-way particle tracking model estimates the sources of marine-debris and times at which marine debris are released.

- Marine-debris outflows from each source are computed using the inverse method.

Method

Inverse method

The relationship between the quantity of marine-debris reaching the actual beach (z) for a certain period and outflows (f) at various sources is expressed as:

the date when marine-debris are released from the source

$$\left(f_1^{M-l},\ f_2^{M-l},\ f_3^{M-l}, \cdots\cdots,\ f_{N-2}^{M},\ f_{N-1}^{M},\ f_N^{M} \right) \begin{pmatrix} g_1 \\ g_2 \\ g_3 \\ \cdot \\ \cdot \\ g_{N\times(l+1)} \end{pmatrix} = z$$

the quantity of marine-debris reaching the actual beach for a certain period

outflows from each source (unknown)

source of marine-debris

Weight of each source outflows (unknown)

the quantity of marine-debris for a certain period → **webcam observation data**

the source of marine-debris → **particle tracking model**

Webcam

To compute the quantity of marine debris that had been washed recently ashore on the beach,

1. Monthly averaged quantities of marine-debris are computed using webcam observation.
2. The increment (difference) of the averaged quantities are computed each month.

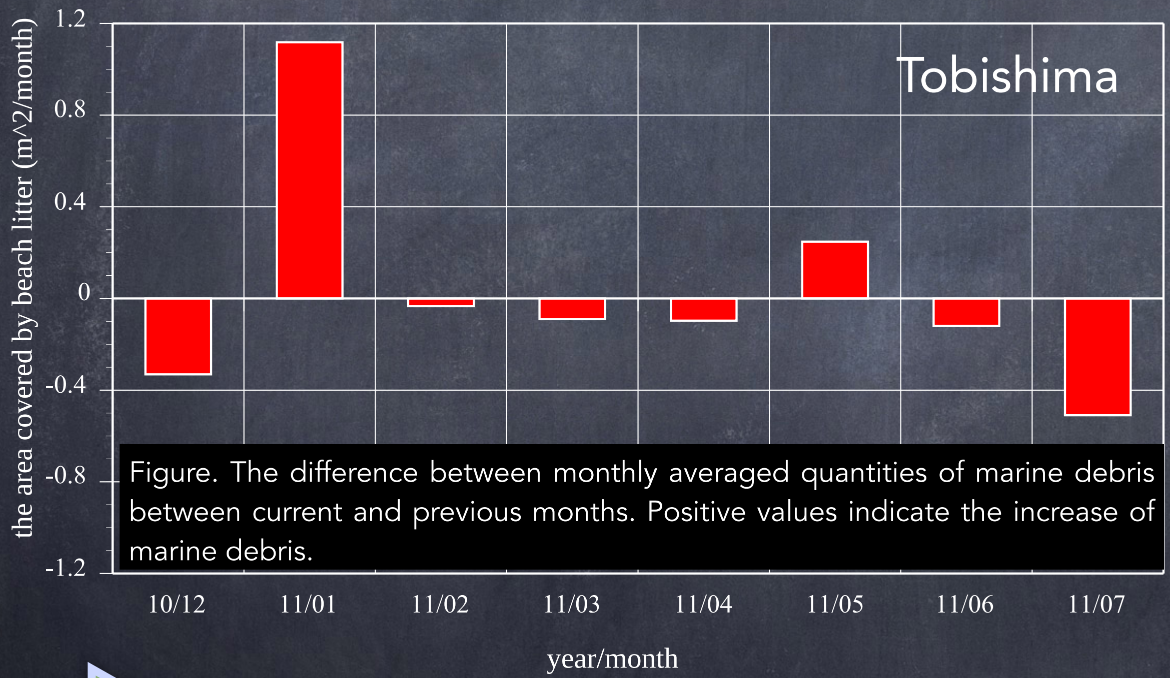


Figure. The difference between monthly averaged quantities of marine debris between current and previous months. Positive values indicate the increase of marine debris.

Marine debris did not always increase with time, presumably because the waves and/or winds cause the re-drifting (the return of marine debris to the ocean)

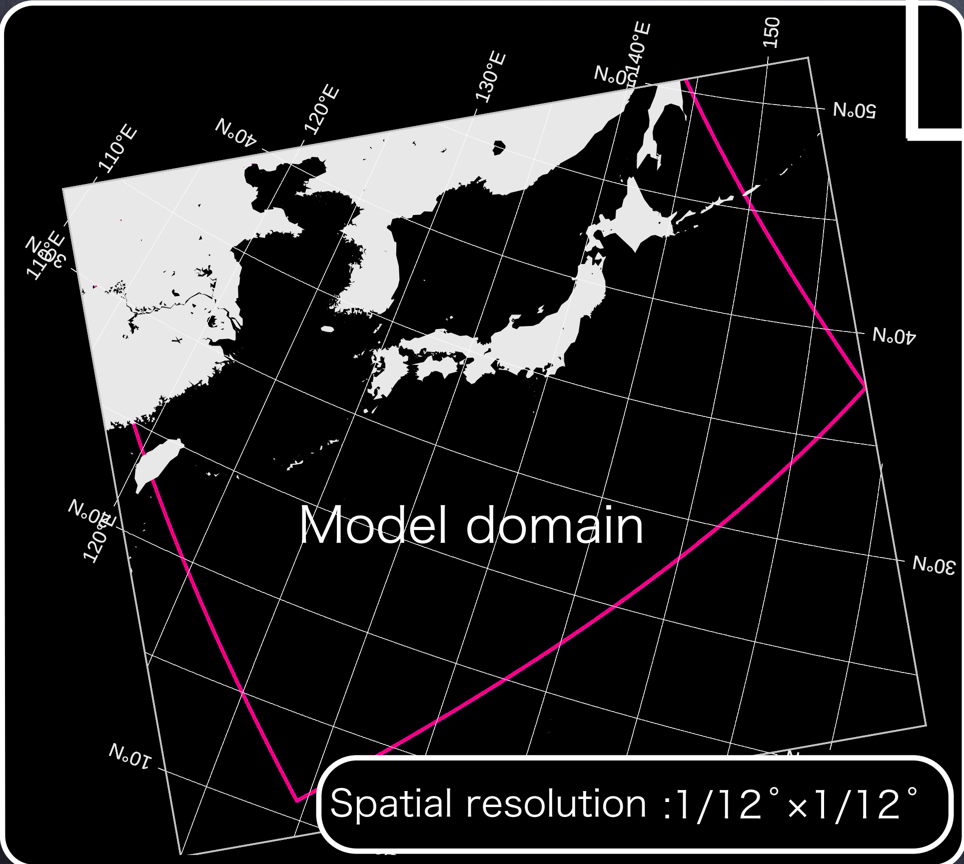
We assumed that the increments were equal to the quantity of marine-debris reaching the beach over the course of one month.

We chose only those months to compute the outflows from each source.

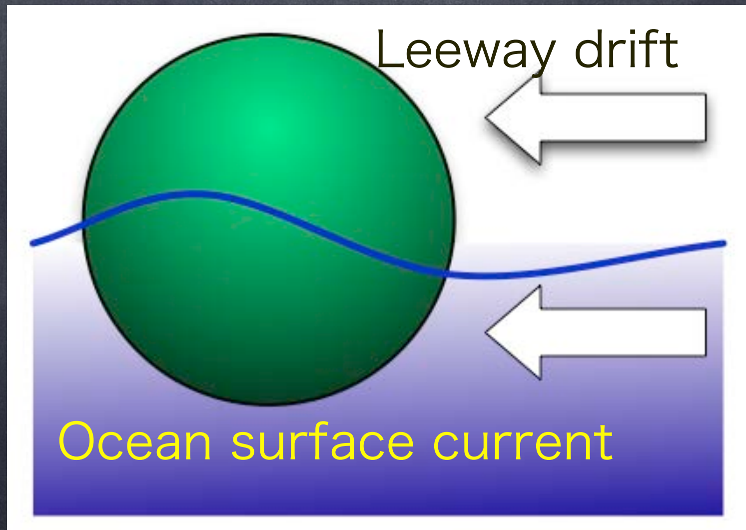
Particle tracking model (PTM; Isobe et al., 2009)

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

- $\mathbf{X}^{t+\Delta t}$: Particle location at time $t+\Delta t$
- $\mathbf{U}$: Current vector
- Δt: Time Step (360s)
- R: Random number
- K_h: diffusivity
- (i, j): unit vector



The modeled particles in the PTM are carried by ambient surface current and leeway drift.



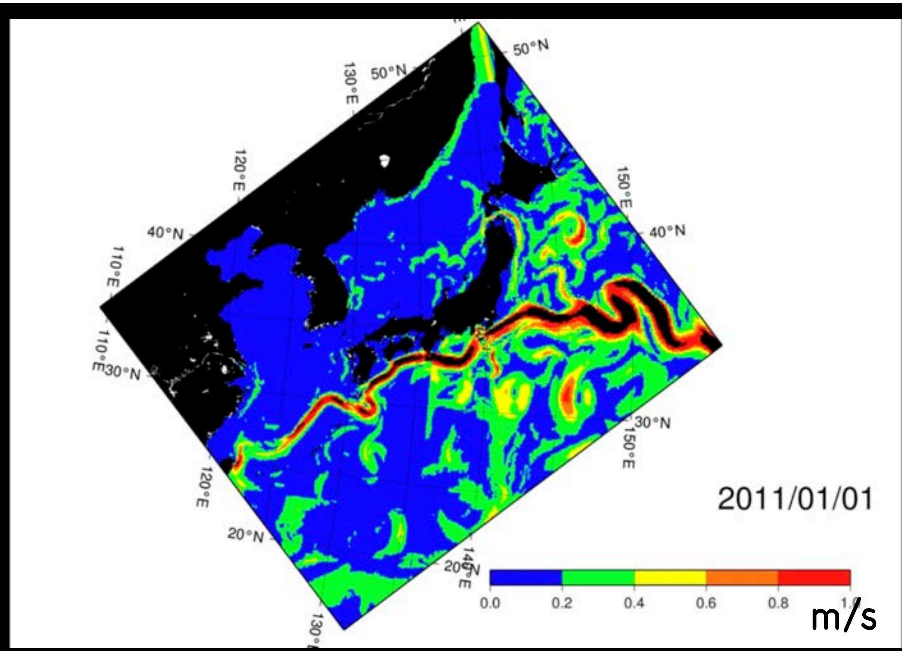
Particle tracking model (PTM)

Ocean surface current data set

Data assimilation research of the East Asian marine system (DREAMS; Hirose et al., 2014)

Spatial resolution: 1/12° (lon.) × 1/15° (lat.)

Time resolution: daily



Leeway drift

The leeway drifts (V) are determined by

$$V = \sqrt{\frac{\rho_a}{\rho_w} \frac{Cd_a}{Cd_w} \frac{A_a}{A_w}} W$$

Density ratio (atmosphere/ocean)

Drag coefficient ratio

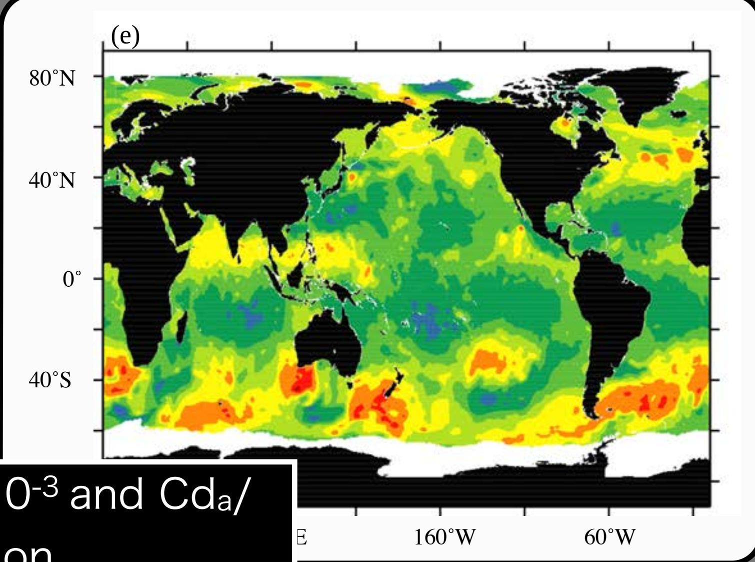
Horizontal projected area

wind speed

- High resolution ASCAT Wind vector data set(Kako et al., 2011)

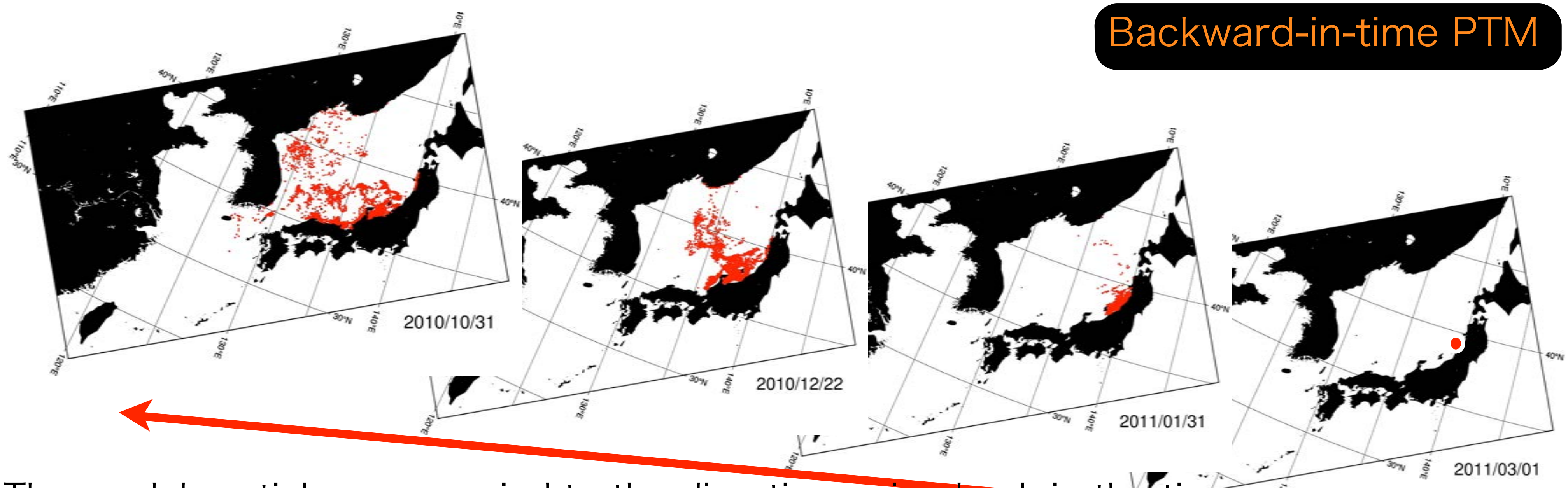
Spatial resolution: 0.25° × 0.25°

Time resolution: daily

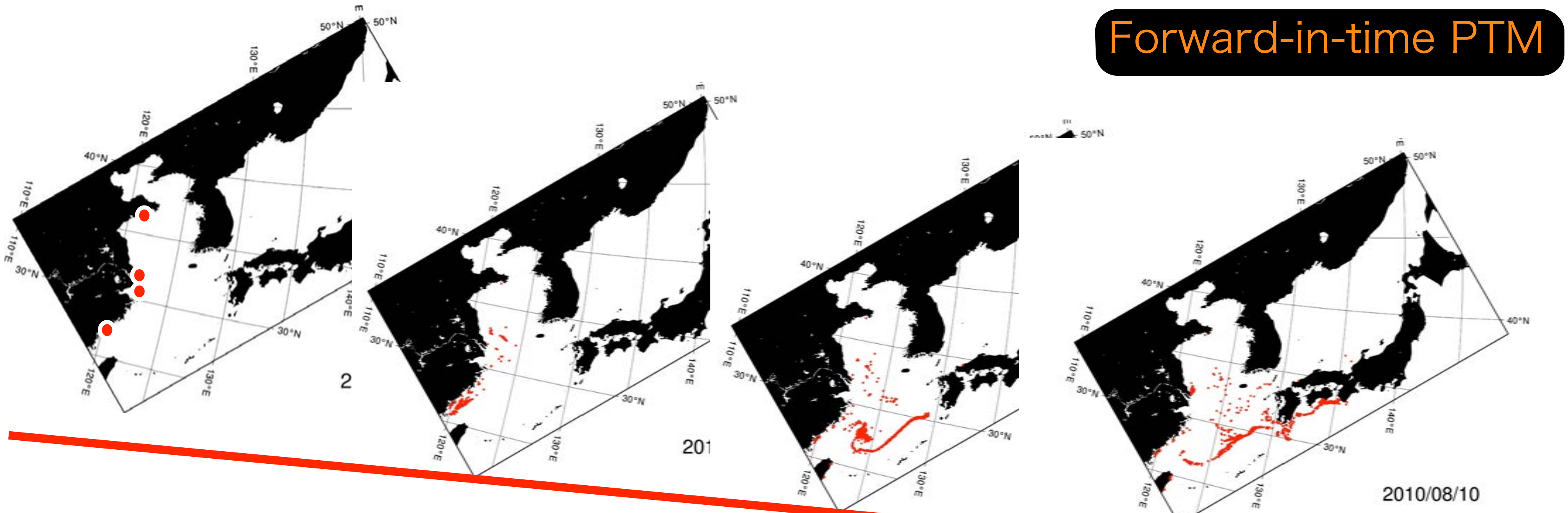


We use values ρ_a/ρ_w=1.15×10^{-3} and Cd_a/Cd_w=1 in the present application.

Two-way PTM (Isobe et al., 2009)



The model particles are carried to the direction going back in the time.



10,000 particles are again released from each source candidate

Result of two-way PTM

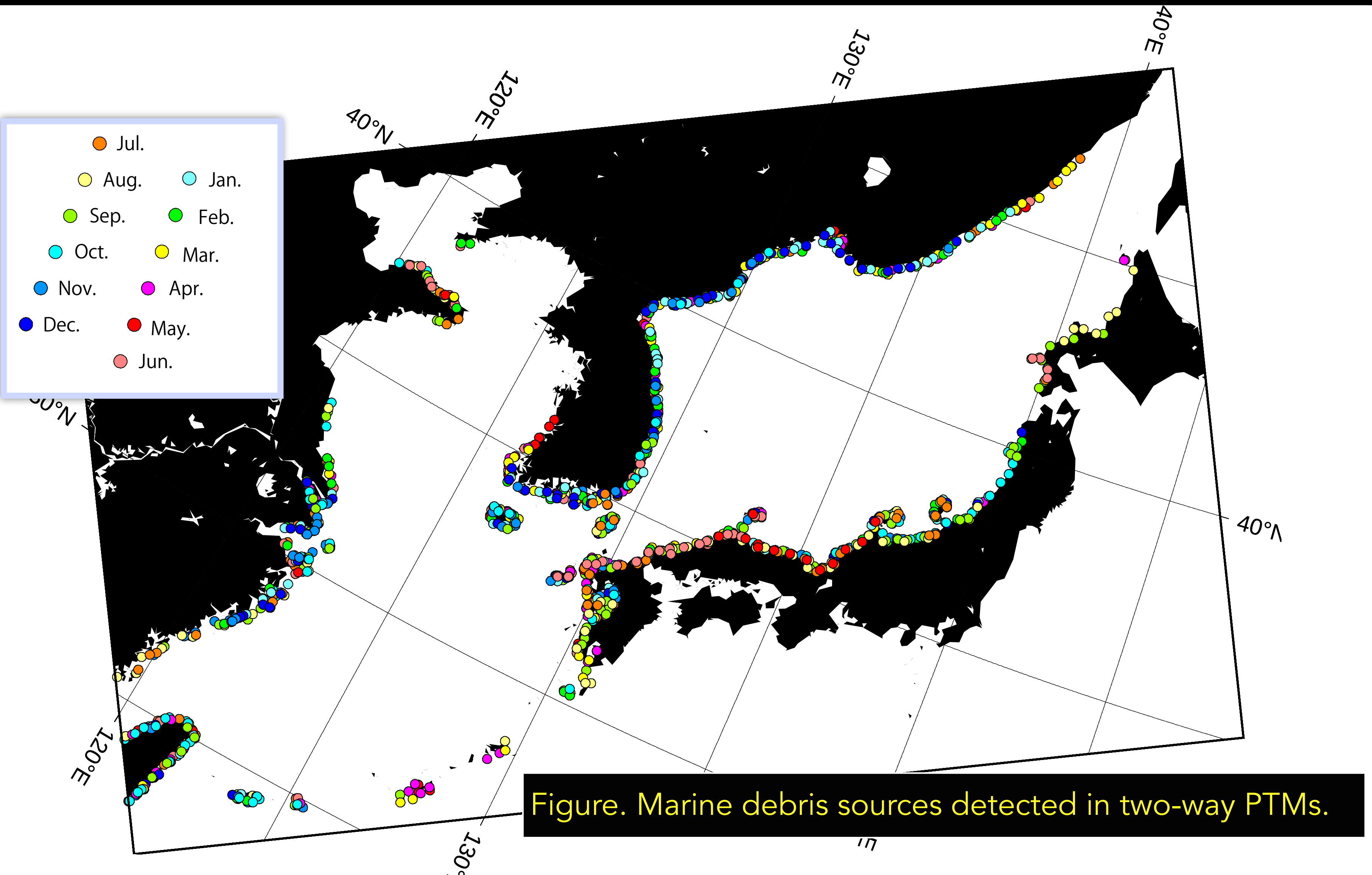
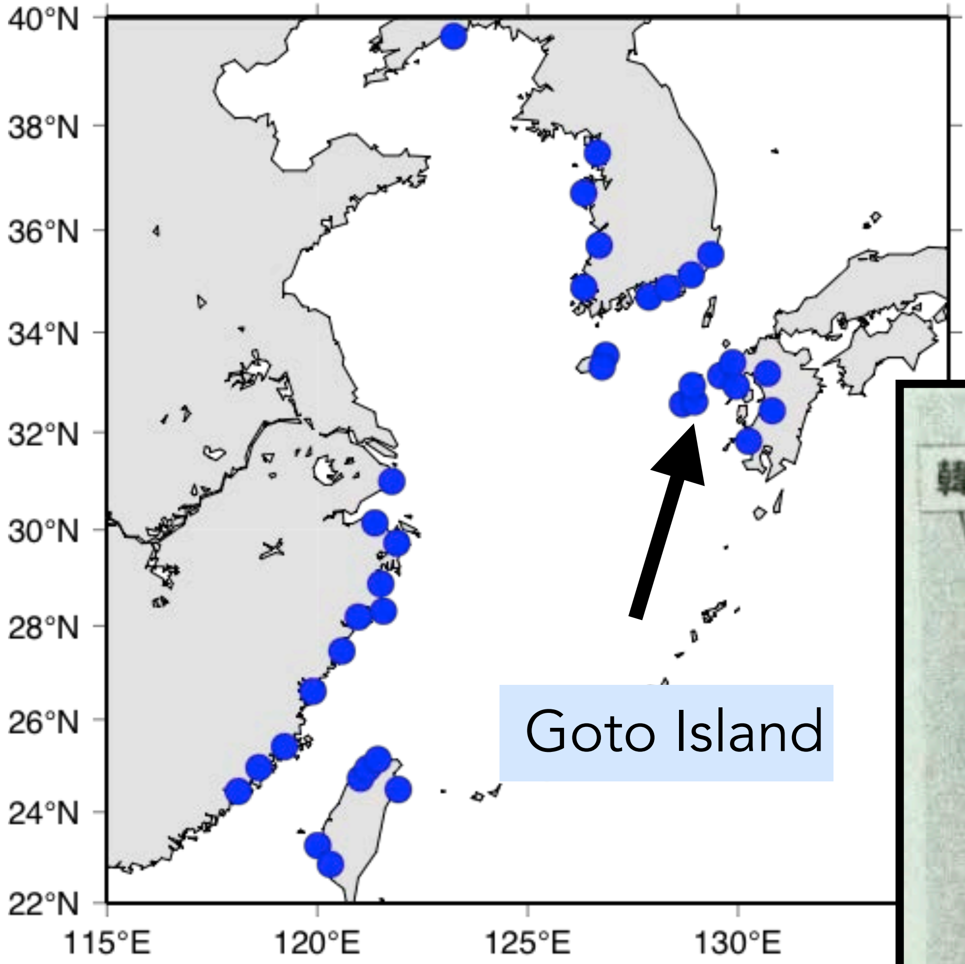


Figure. Marine debris sources detected in two-way PTMs.

The capability of the two-way PTM to identify the marine debris sources has already been presented in Kako et al. (2010)

Validation of two-way PTM (Kako et al., 2010)

(a)disposal-lighter sources detected by phone number printed on the surface



Validation of two-way PTM (Kako et al., 2010)

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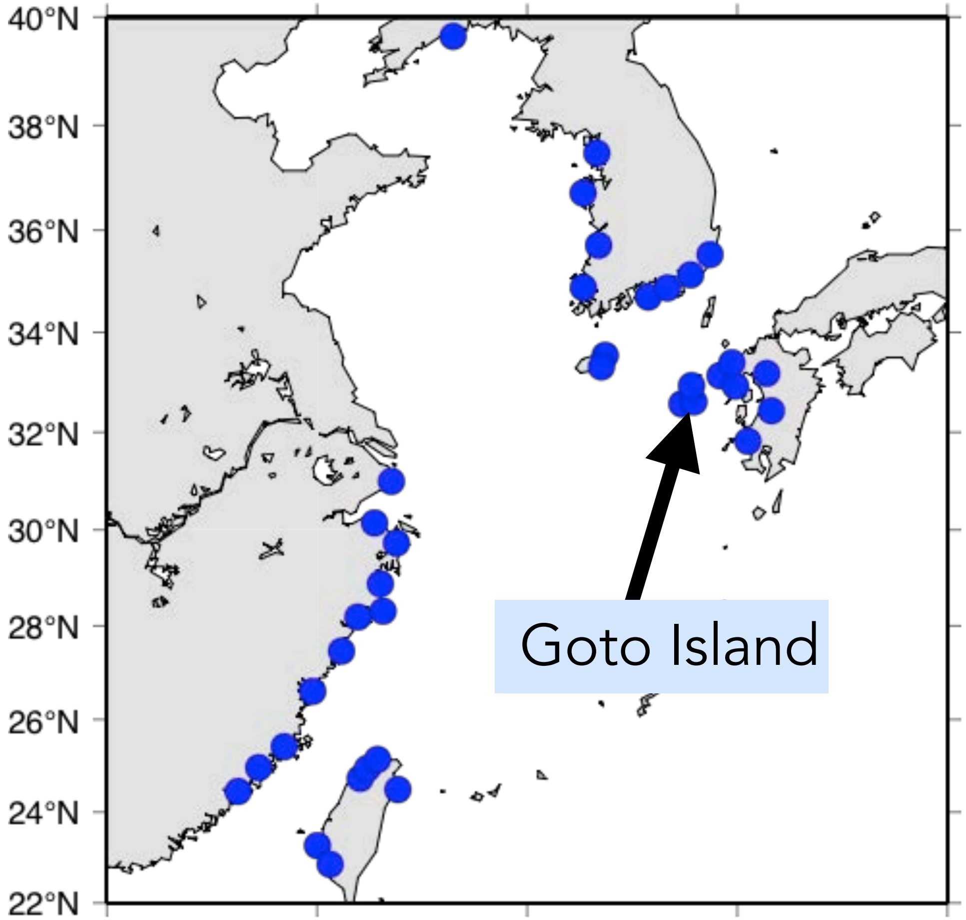
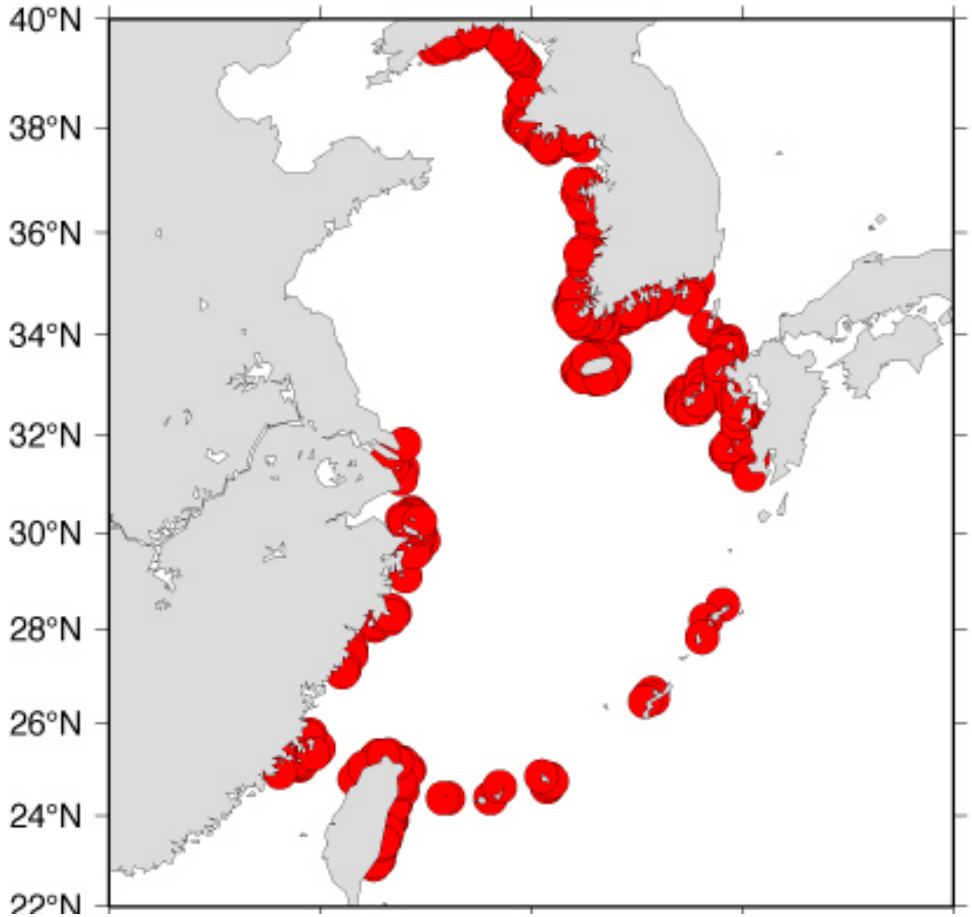
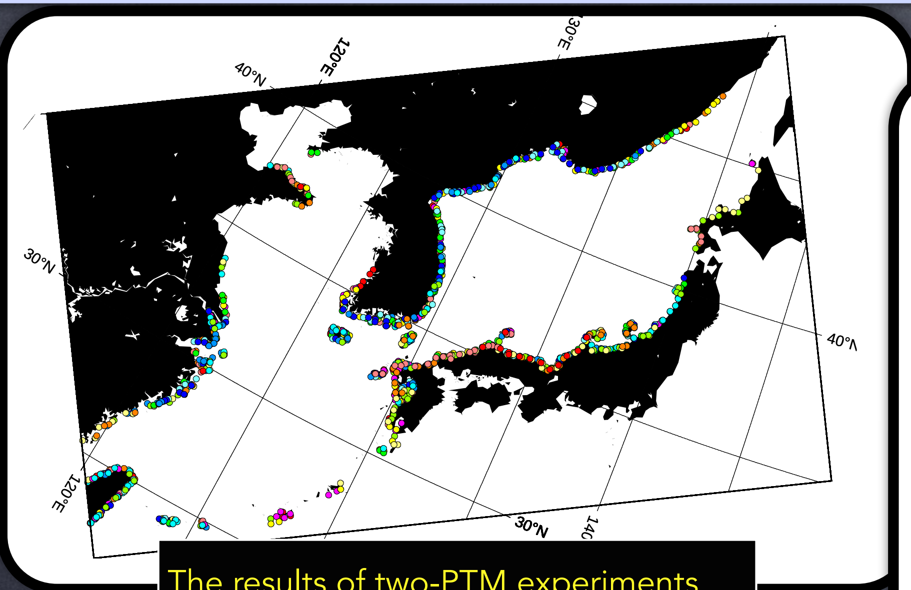


(b)disposal-lighter sources detected by two-way PTM in Kako et al. (2010).

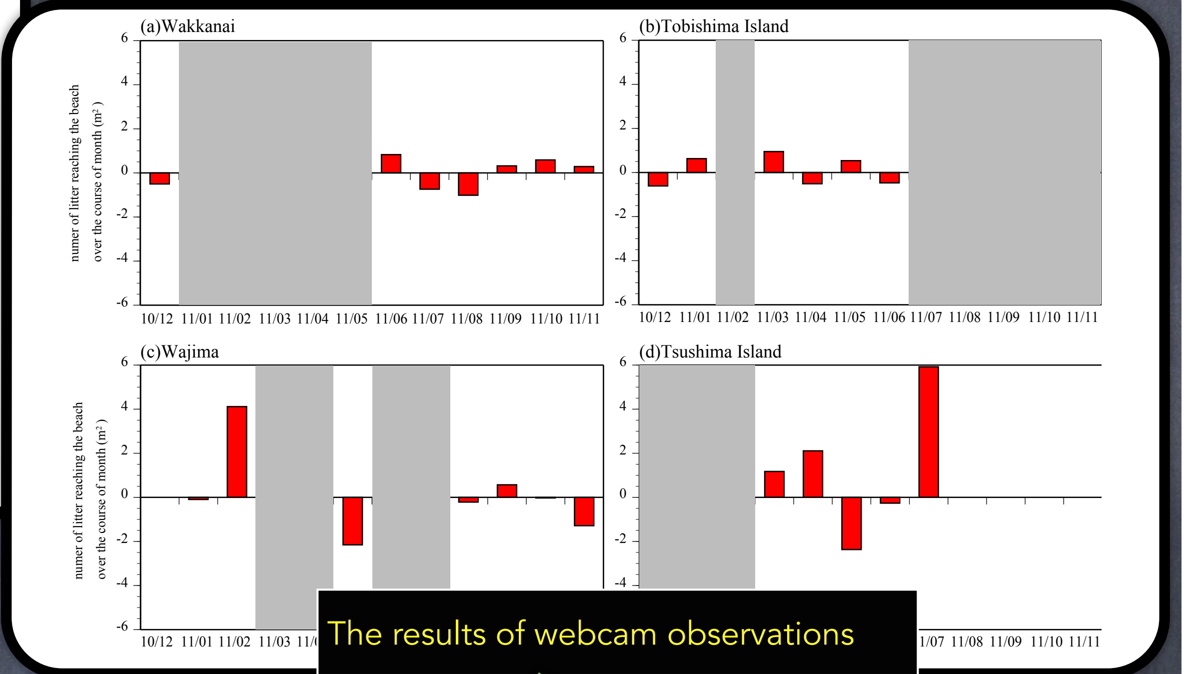


The two-way PTM used in this study is capable of computing the source of marine debris.

Inverse method



The results of two-PTM experiments



The results of webcam observations

$$\left(f_1^{M-l}, \quad f_2^{M-l}, \quad f_3^{M-l}, \cdots\cdots, \quad f_{N-2}^{M}, \quad f_{N-1}^{M}, \quad f_N^{M} \right) \begin{pmatrix} g_1 \\ g_2 \\ g_3 \\ \cdot \\ \cdot \\ g_{N\times(l+1)} \end{pmatrix} = z$$

We attempt to estimate the outflows at each source using an inverse method with a Lagrange multiplier.

Inverse method

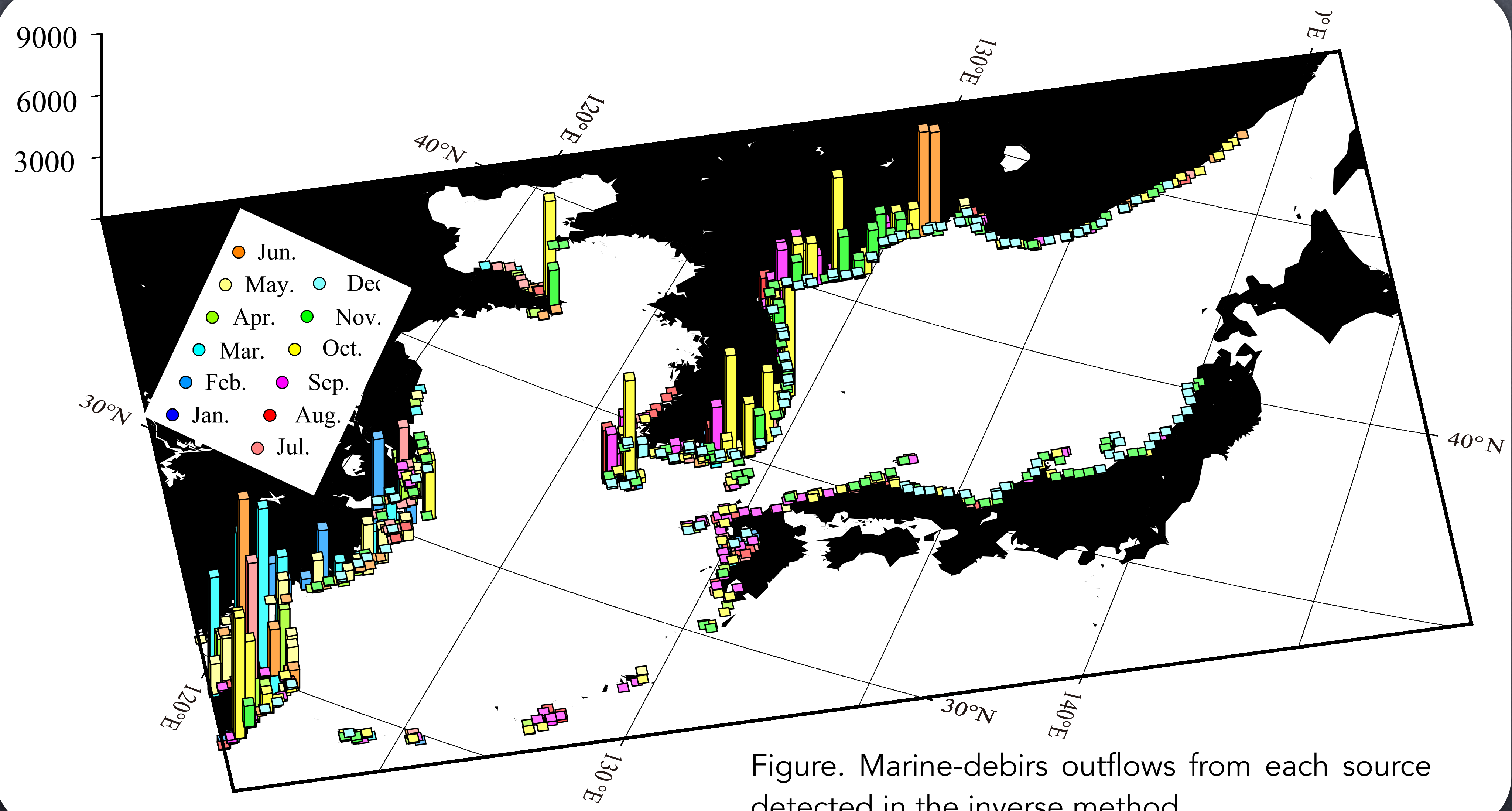


Figure. Marine-debirs outflows from each source detected in the inverse method.

The same number of particles derived from the inverse method are released in each month/ source using the forward-in-time PTM

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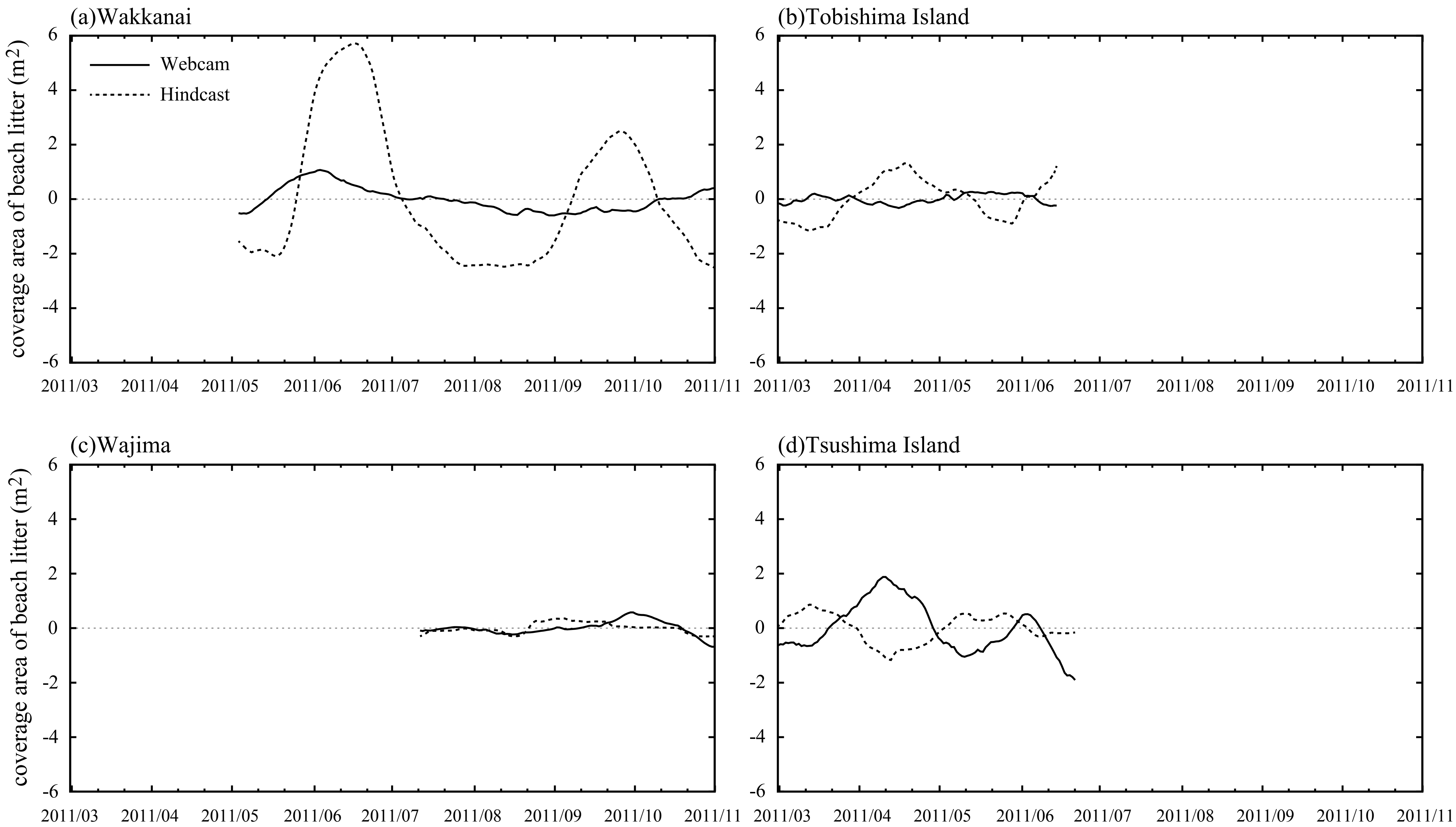
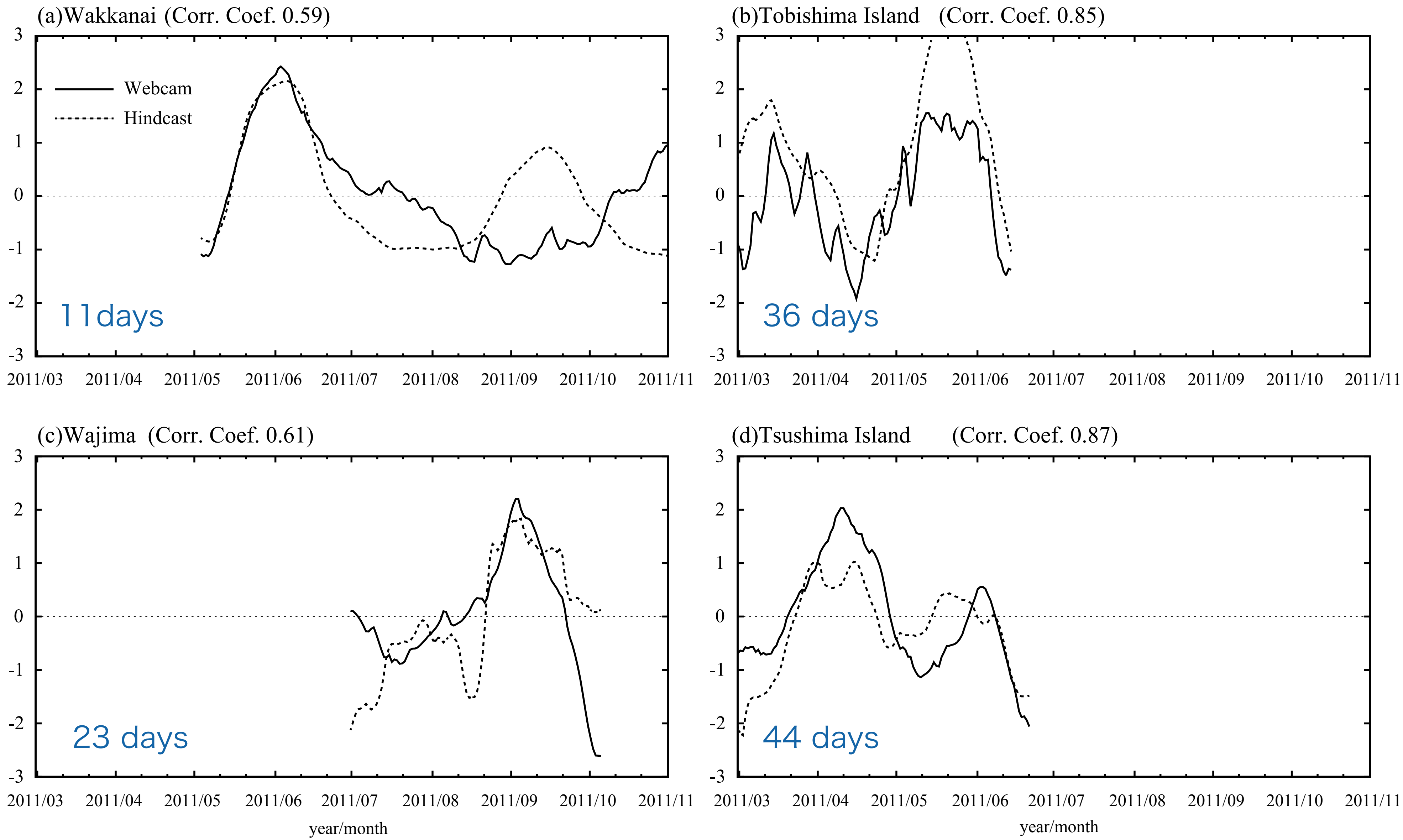
The number of particles reaching the modeled beaches are compared with those obtained in the webcam.

Comparison of hindcasted quantities with webcam observations



Model results are inconsistent with the observed results.

Comparison of hindcasted quantities with webcam observations



Summary

- We obtain an outflow map of marine-debris using an inverse method in conjunction with the two-way PTM approach and webcam observations.
- Given these marine-debris outflows from each source, we hindcast the quantity of litter reaching the beaches where webcam are placed on.
- Hindcasted variation of the quantity of marine-debris is consistent with the actual variation of that of marine-debris with the about 30-day time lag between the modeled and observed time series.
- Possible causes of this time lag remain ambiguous because the temporal variation shorter than 1 month is unresolved in the present PTM.