海洋漂流物のモデルシミュレーション

Model Simulation of Japan Tsunami Marine Debris (JTMD)

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Plan of the presentation　話の内容

The largest "island" of debris stretches 60 nautical miles (69 miles) in length and covers an expanse of more than 2.2 million square feet, according to the US Navy's 7th Fleet, which is closely monitoring the floating rubbish
Picture: REUTERS

1.Introduction　はじめに

2. Data Assimilation System: MOVE and K7
海洋のモデル、データ同化システム

3. Modelling of Drifting JTMD and Examples of the Model Solution
漂流予測と結果

4. Summary　まとめ

I. INTRODUCTION

Tragic event of the March 11, 2011 tsunami in Japan has generated estimated 1.5 million tons of debris floating off the eastern Honshu (Japan Ministry of Environment, 2014).

This is an amount comparable to the annual budget of plastic marine debris of the entire North Pacific (Jambeck et al., 2015).

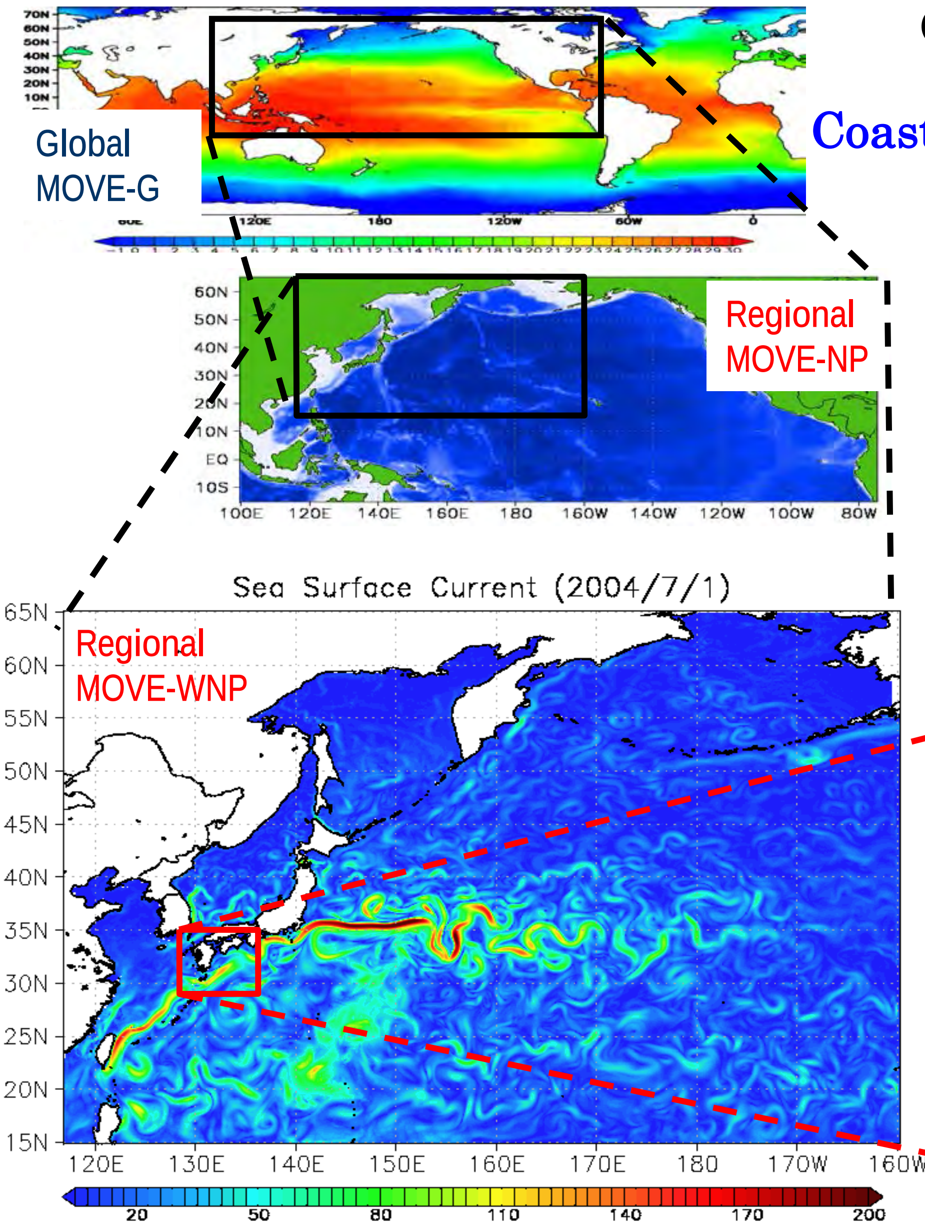
This Japan Tsunami Marine Debris (JTMD) was seen on photographs in the coastal areas.

Several weeks later, after JTMD drifted off shore and dispersed, its monitoring became very difficult.

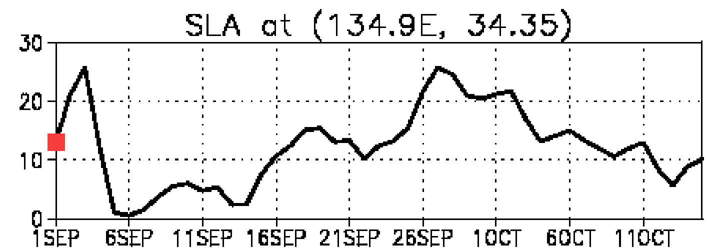
Sparse reports from the sea were not able to provide a coherent description of the pattern and drift motion of JTMD and this task was adopted by numerical models.

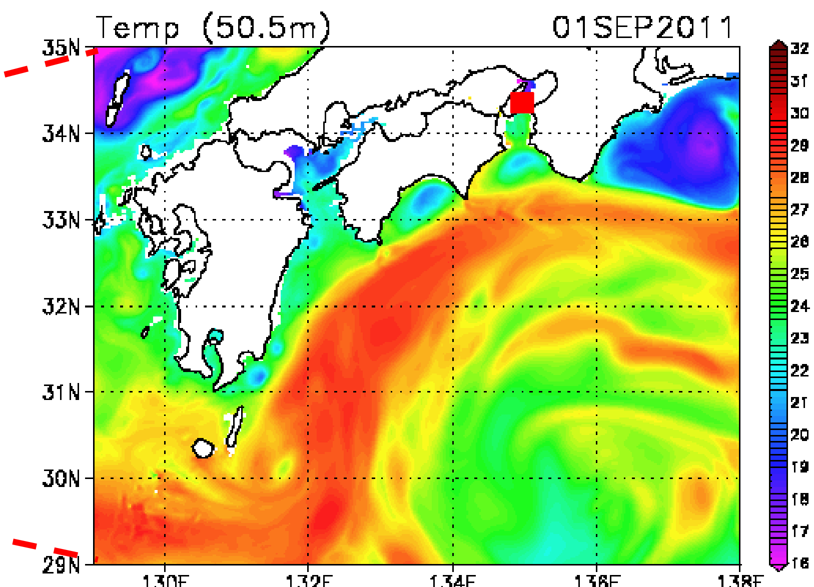
JMA/MRI systems

GlobalWarming, Seasonal-ElNino (Global, 1°)
Ocean Weather (N. Pac, 1/2°~1/10°)
Ocean Weather (W.N. Pac, 0.1°~)
Coastal mdl (Seto, Jpn, Tohoku-SICAT02:2km)



Coastal Application: Abnormal High Tide





JMA/MRI Ocean Data Assimilation System

MRI MOVE/MRI.COM (Multivariate Ocean Variational Estimation) system

OGCM: MRI.COM (MRI Community Ocean Model) (similar to MOM)

Method: Multivariate 3D-VAR, 4D-VAR

with vertical coupled T-S Empirical Orthogonal Function (EOF) modal decomposition with area partition (control variable: amp. of EOF mode)
horizontal Gaussian function (inhomogeneous decorrelation scales)
nonlinear constraints (dynamic QC, density inversion) bias correction

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^T \mathbf{B}_v^{-1}(\mathbf{x}-\mathbf{x}^b) + \frac{1}{2}\left[\mathbf{Hx}-\mathbf{y}^{\mathrm{TS}}\right]^T \mathbf{R}^{-1}\left[\mathbf{Hx}-\mathbf{y}^{\mathrm{TS}}\right] + \frac{1}{2\sigma_h^2}\left[\mathcal{H}(\mathbf{x})-\mathbf{y}^{\mathrm{SSH}}\right]^T\left[\mathcal{H}(\mathbf{x})-\mathbf{y}^{\mathrm{SSH}}\right]$$

Source (observation) Data:

Satellite Altimetry (TOPEX/POSEIDON, ERS-1 &-2, ENIVISAT, Jason),

SST (COBESST or GHRSST),

in situ T & S (GTSPP, ARGO, Tao/Triton, drifter),

with QC in each data centers

Atmospheric forcing (Output of Numerical Weather Prediction

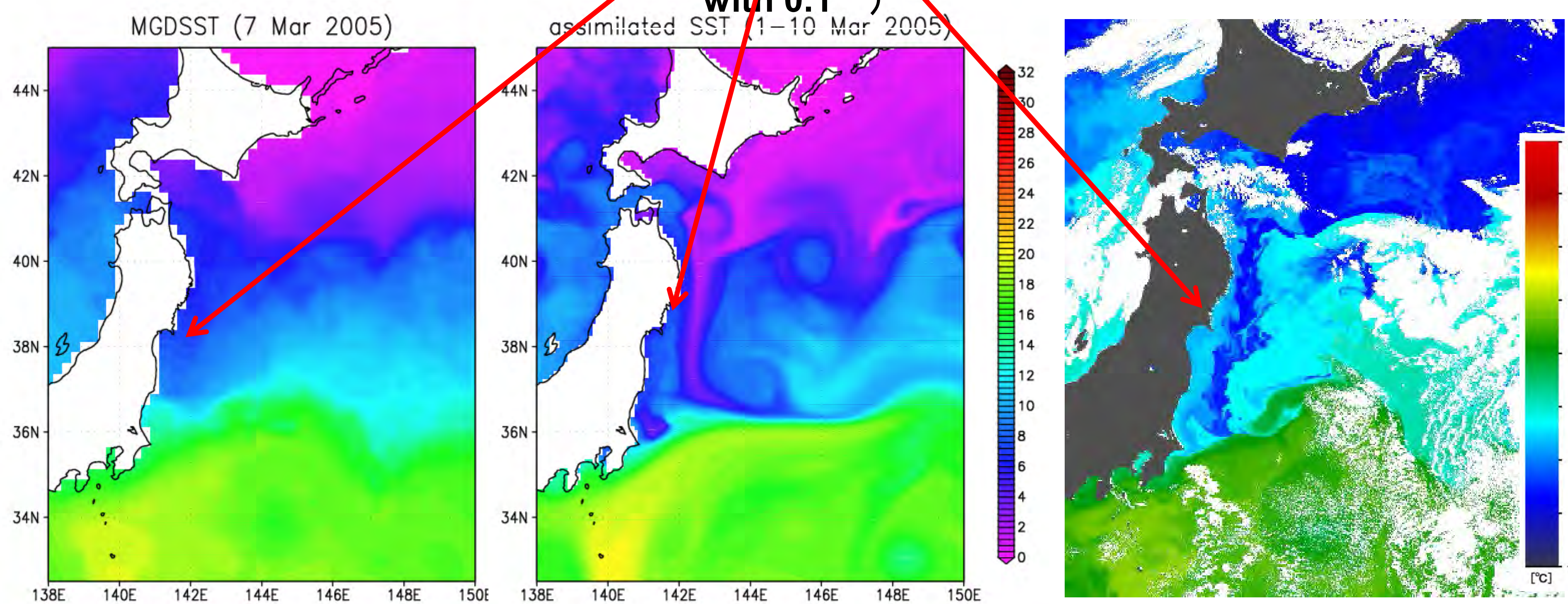
or Atmospheric Reanayses: JRA55)

Snapshot of SST（March 7, 2005） offshore of Target areas (Tohoku)

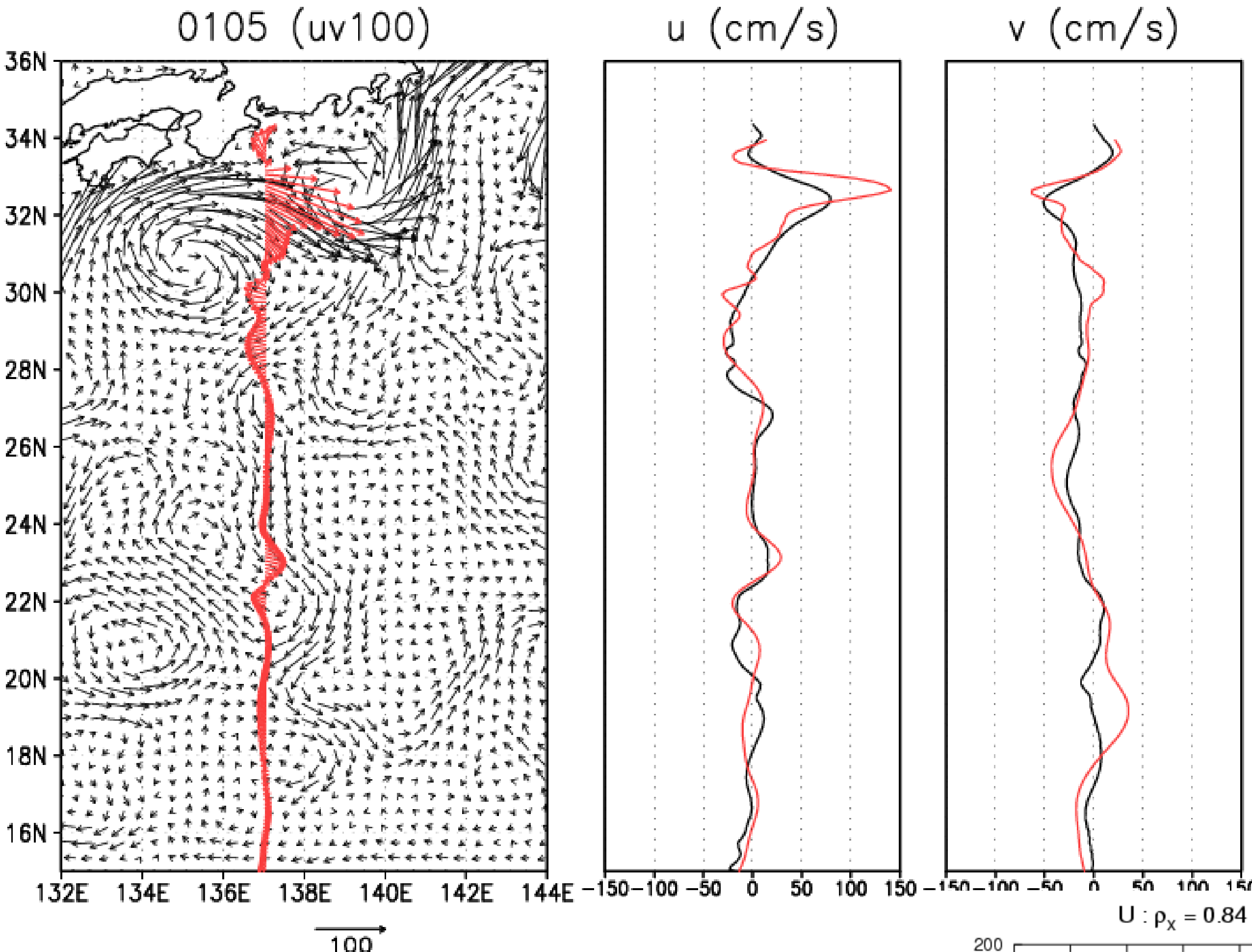
MGDSST
（statistical 1/4°）

MOVE / MRI.COM
（data assimilation with 0.1°）

Terra/Aqua MODIS
（satellite OBS）



Validation

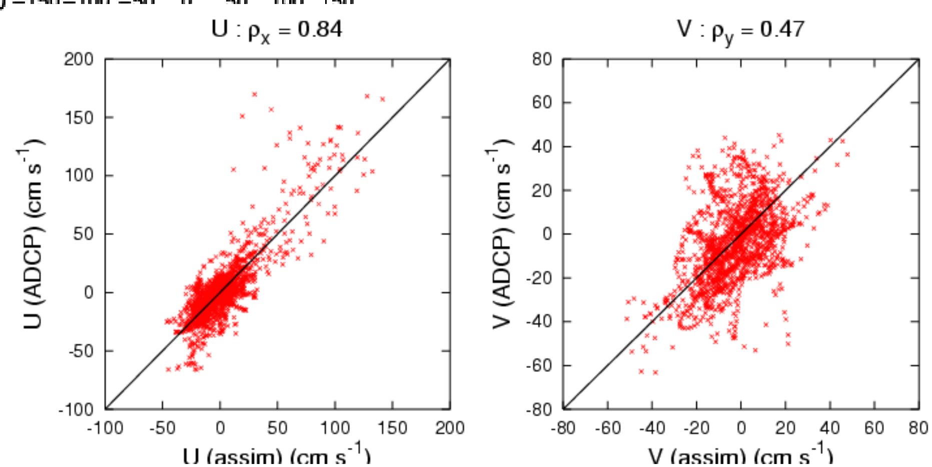


Horizontal Velocity

2005/1

Black: Assim (MOVE)

Red: Independent Obs. (ADCP)



Correlation Coefficient

V variability is smaller->difficult

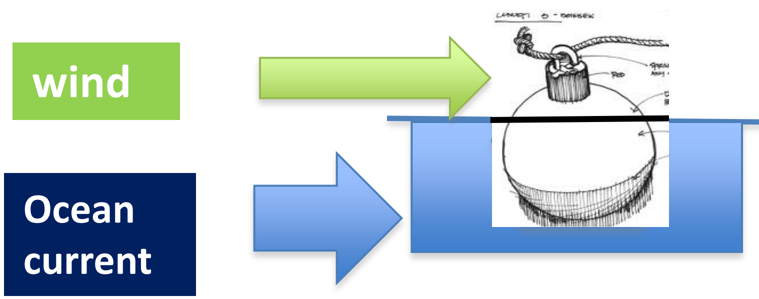
Dynamic framework of Particle tracking粒子を流す方式

$$x_{t+\Delta t} = x_t \quad + \quad u_m \Delta t \quad + \quad \delta x$$

(時間発展)　(移流)　(乱流拡散)

u_m **Particle Movement by** = **Ocean current** + **Wind – force velocity**

Wind-driven effect for particle movement



Square measure of cross-section above sea surface: A

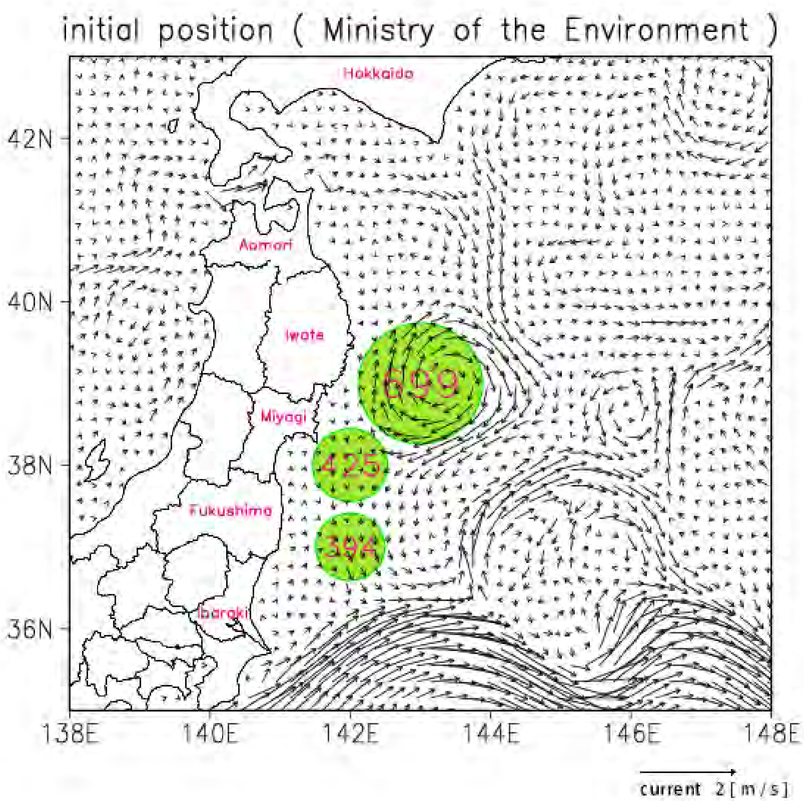
Square measure of cross-section beneath sea surface: B

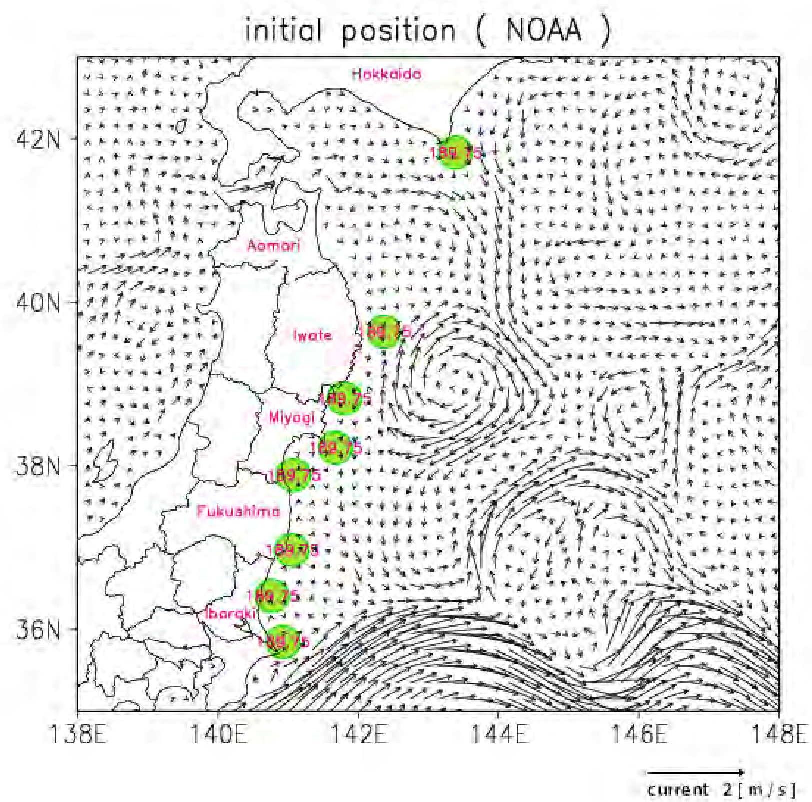
Wind force velocity = $k\sqrt{\frac{A}{B}} \times W_{10}$

windage ↗ **sea surface wind velocity** ↑

Forecast runs for 4 windage cases
k=0.025
A:B=windage%
0:1=0% Low windage
1:1=2.5%
2:1=3.5%
4:1=5.0% High windage

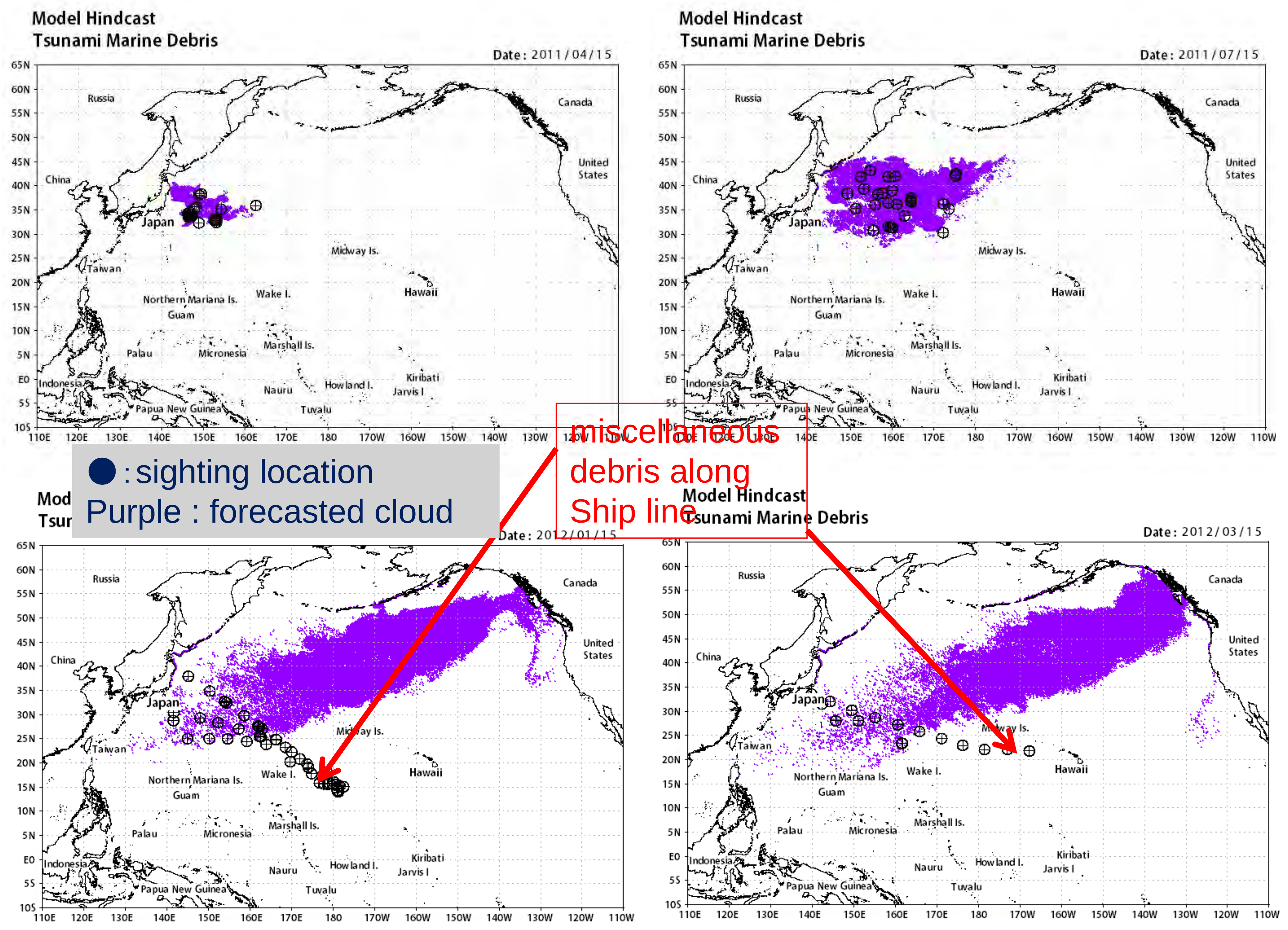
Dependency to initial deployment





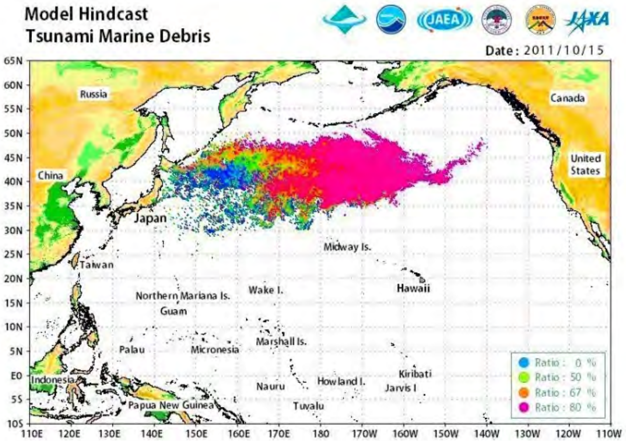
Realistic initial deployment reported by Ministry of the Environment

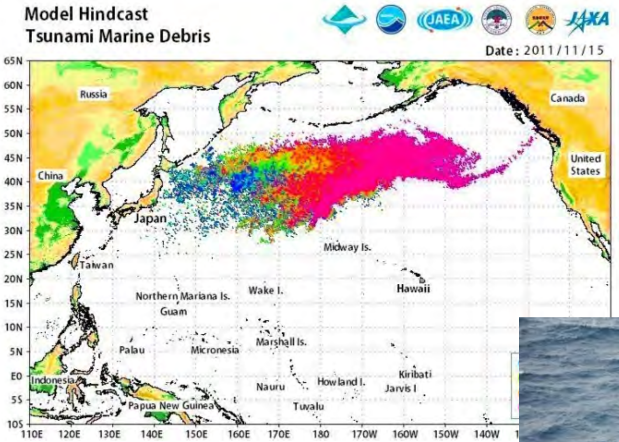
NOAA initial deployment case

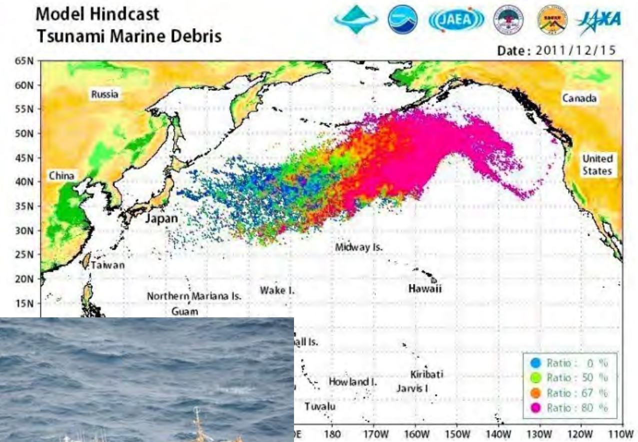


Model Hindcast
Tsunami Marine Debris
Date : 2011/04/15
Model Hindcast
Tsunami Marine Debris
Date : 2011/07/15
Model Hindcast
Tsunami Marine Debris
Date : 2012/01/15
Model Hindcast
Tsunami Marine Debris
Date : 2012/03/15
● : sighting location
Purple : forecasted cloud
miscellaneous debris along Ship line
Russia
Canada
China
United States
Japan
Taiwan
Midway Is.
Hawaii
Wake I.
Northern Mariana Is.
Guam
Palau
Micronesia
Marshall Is.
Indonesia
Nauru
Howland I.
Kiribati
Jarvis I
Papua New Guinea
Tuvalu

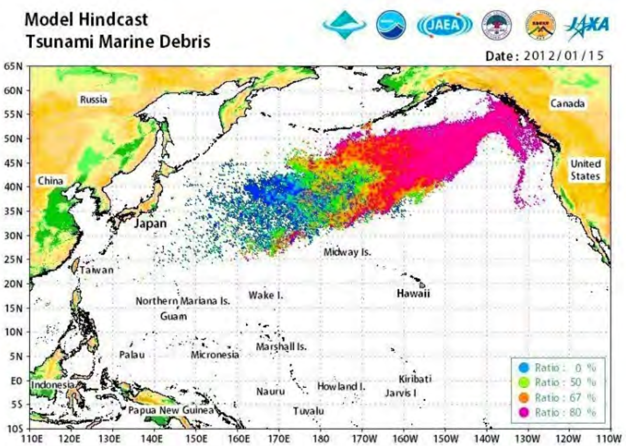
forecast（Oct. 2011 ～ March 2012）: time-series of all forecast cases: overlapped

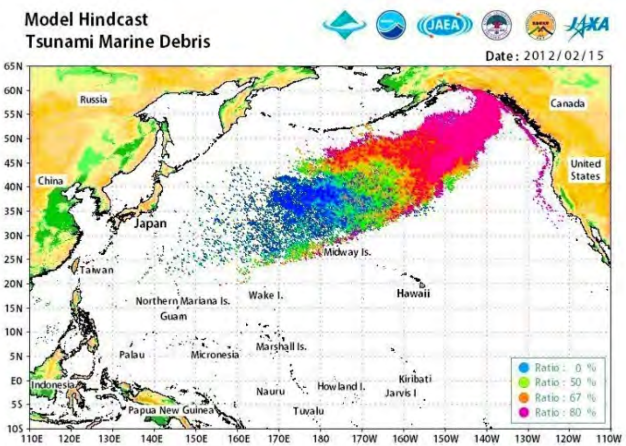


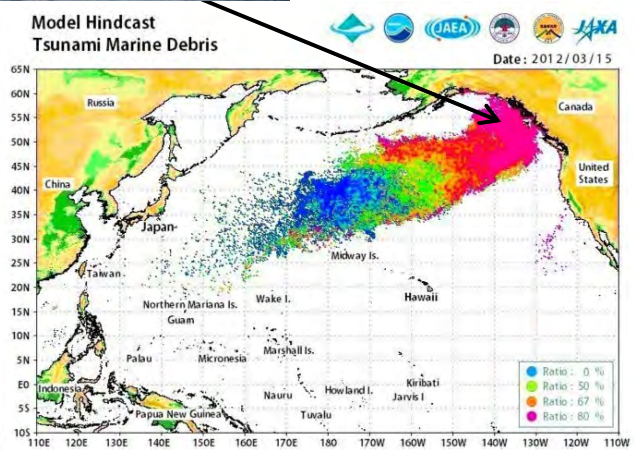




robust agreement

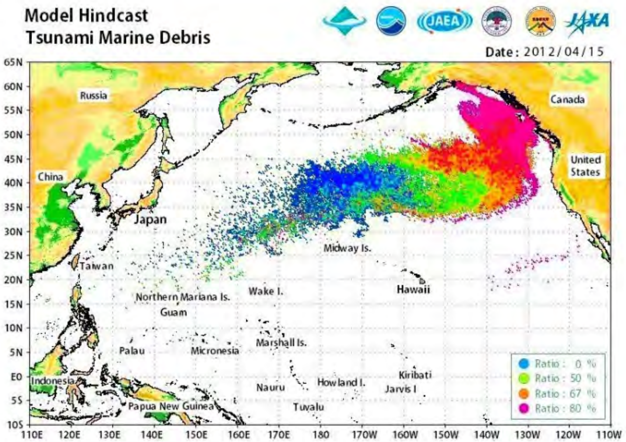


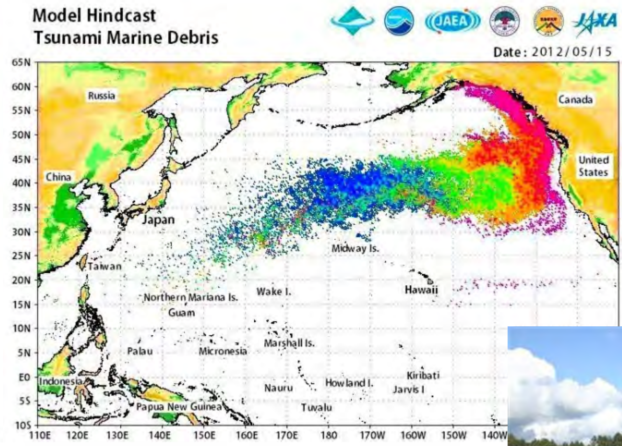


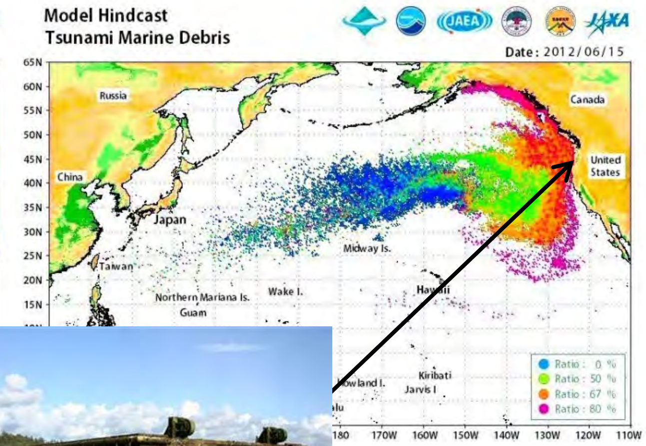


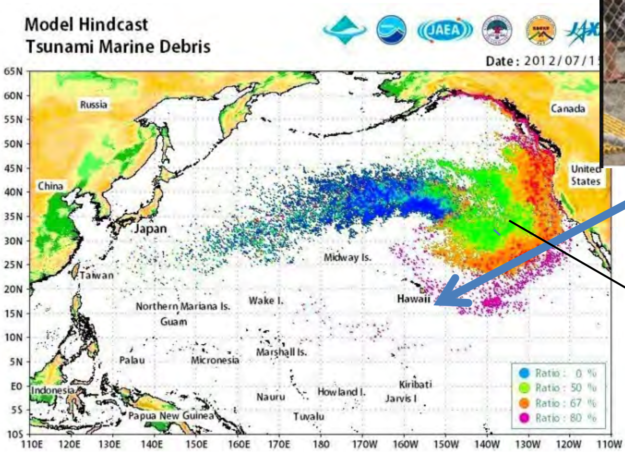
Ratio		beneath : above (the sea surface)		windage
Ratio : 0%	–>	1 : 0	–>	0.0 %
Ratio : 50%	–>	1 : 1	–>	2.5
Ratio : 67%	–>	1 : 2	–>	3.5
Ratio : 80%	–>	1 : 4	–>	5.0

forecast（Apr. 2012 ～ July 2012）: time-series of all forecast cases: overlapped





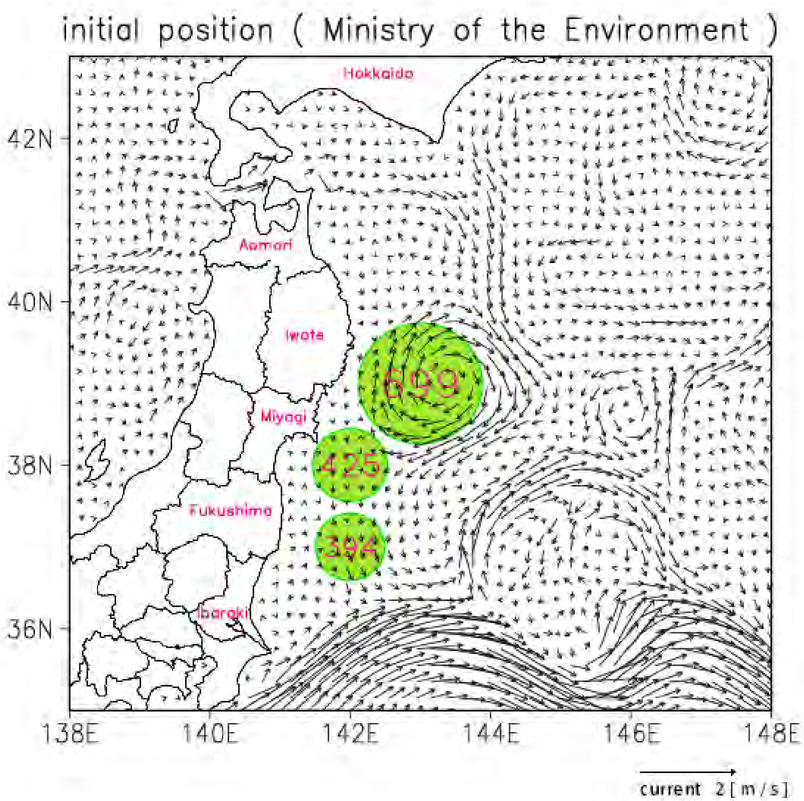




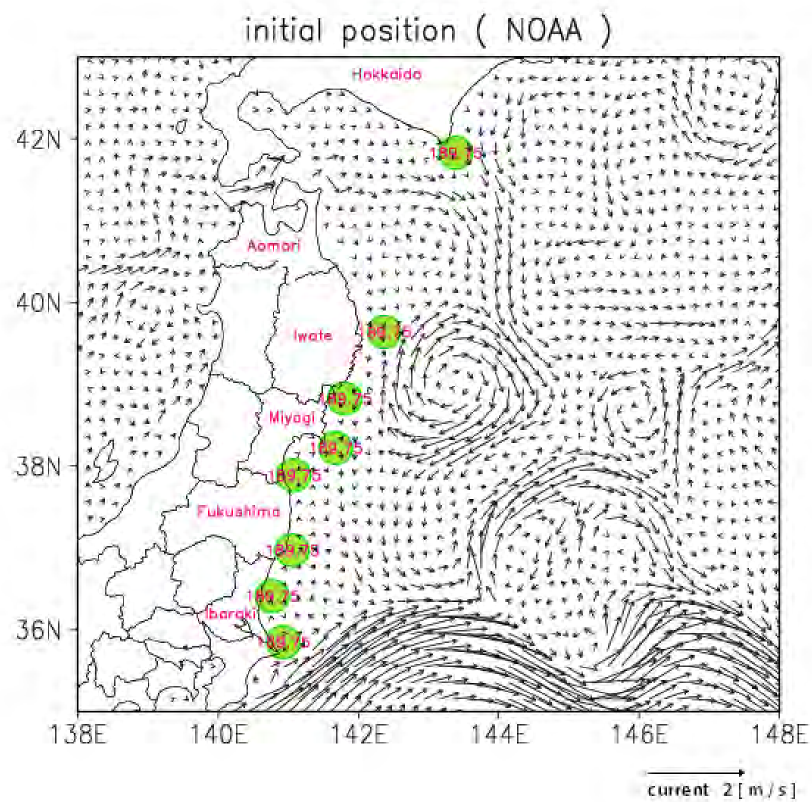
Convergence area
“Garbage Patch”

Ratio		beneath : above (the sea surface)		windage
Ratio : 0%	->	1 : 0	->	0.0 %
Ratio : 50%	->	1 : 1	->	2.5
Ratio : 67%	->	1 : 2	->	3.5
Ratio : 80%	->	1 : 4	->	5.0

Dependency to initial deployment



Realistic initial deployment reported by Ministry of the Environment



NOAA initial deployment case

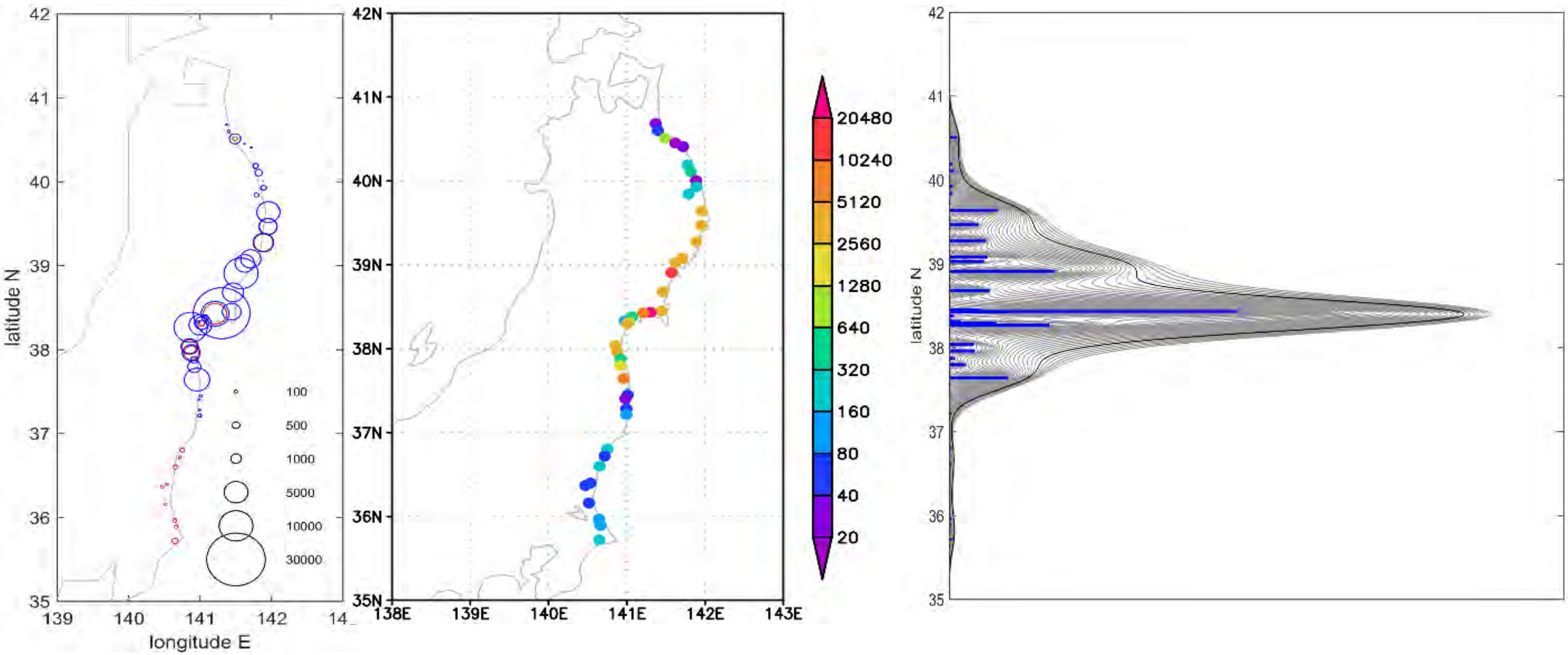


Figure 1. (a) Number of broken homes, reported by municipal sources (blue) and Asahi Shimbun (red). (b) Composite data distribution. (c) 'Source function' of JTMD calculated with a variety of filter and used to initiate model simulations.

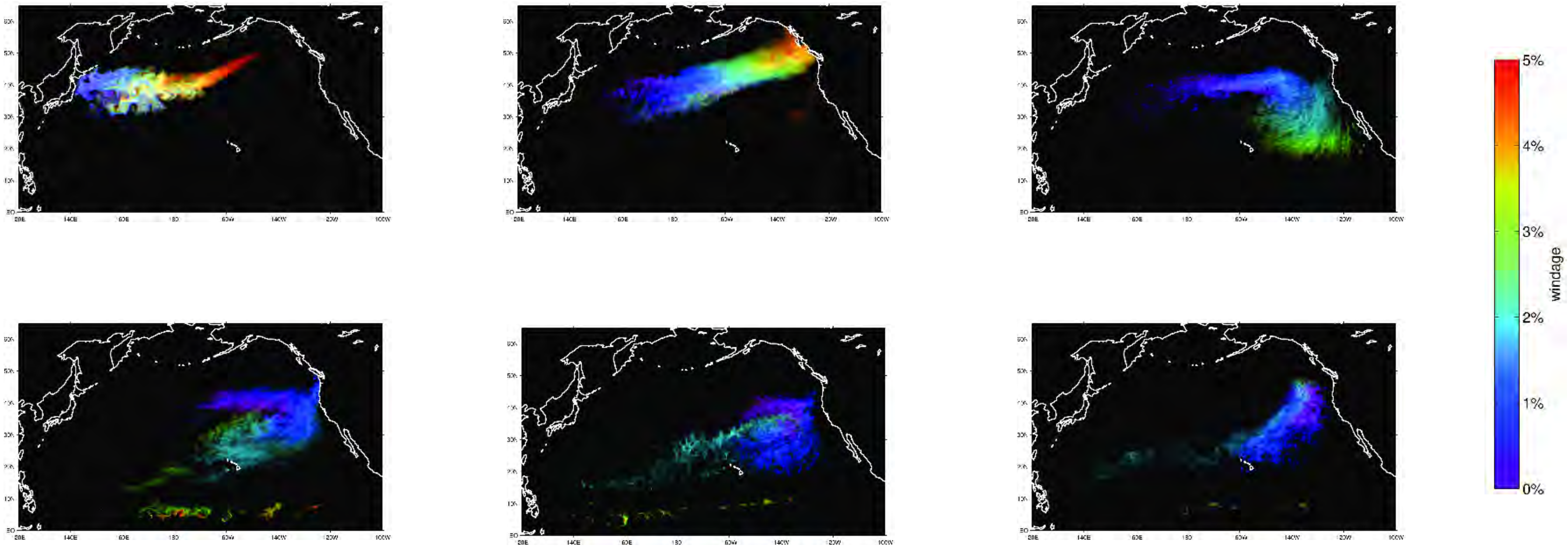


Figure 5. Evolution of JTMD tracer in the SCUD model simulations. Colors indicate windage of the debris. Shown are maps, corresponding to September 1, 2011, March 1, 2012, September 1, 2012, March 1, 2013, September 1, 2013, and March 1, 2014.

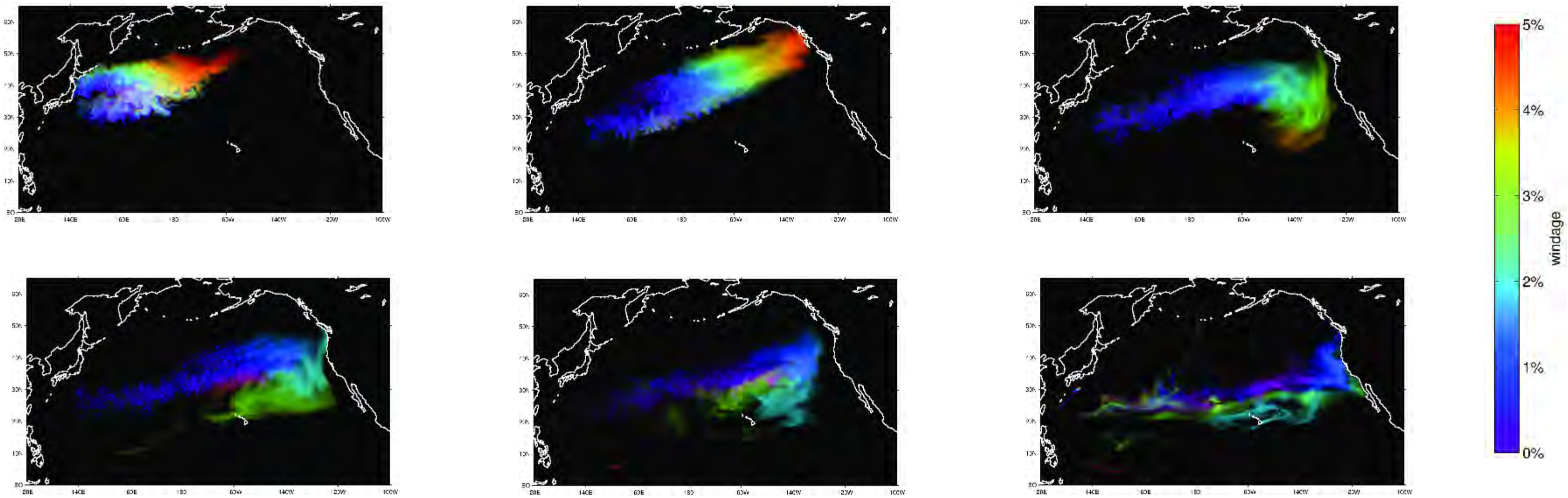


Figure 6. Same as in Figure 5 but for but for MOVE/K-7/SEA-GEARN model simulations.

米国海洋大気庁(NOAA）のシミュレーションシステム(GNOME)による結果

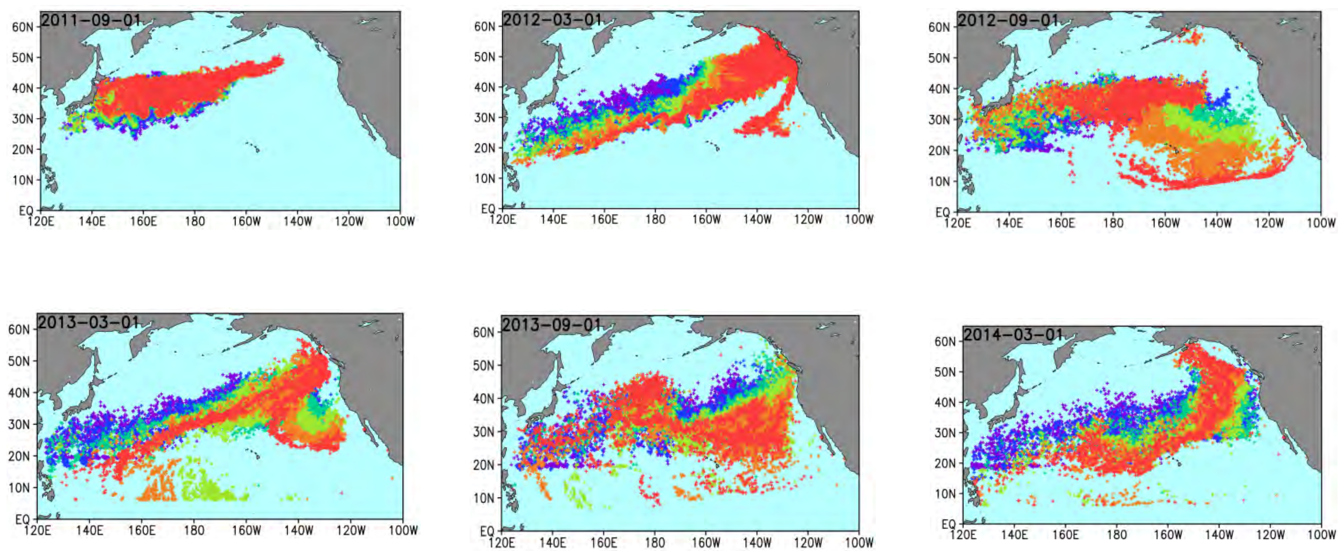
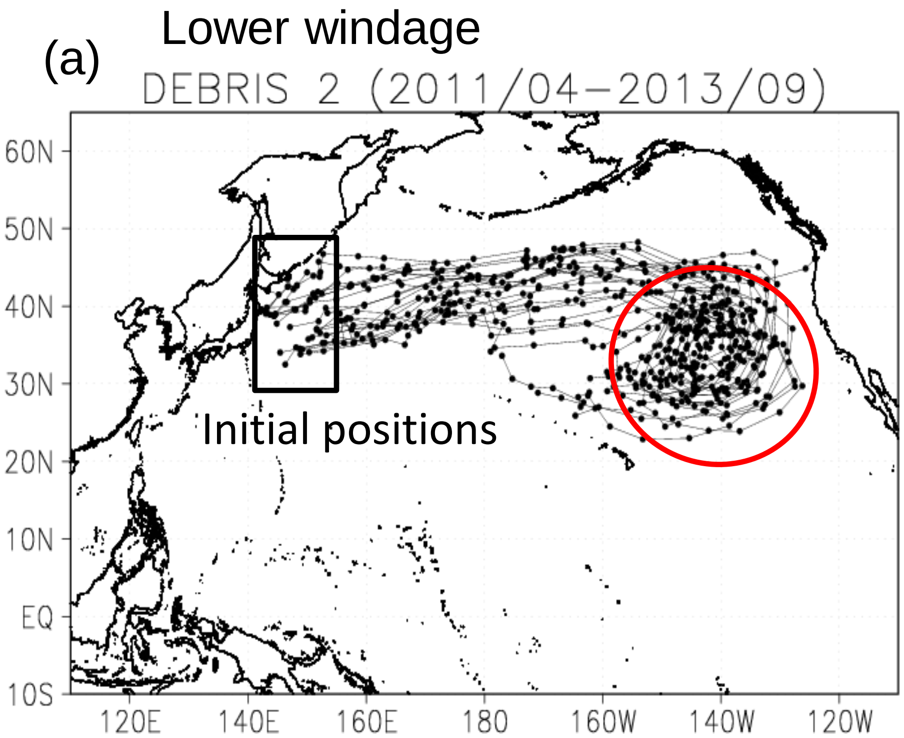
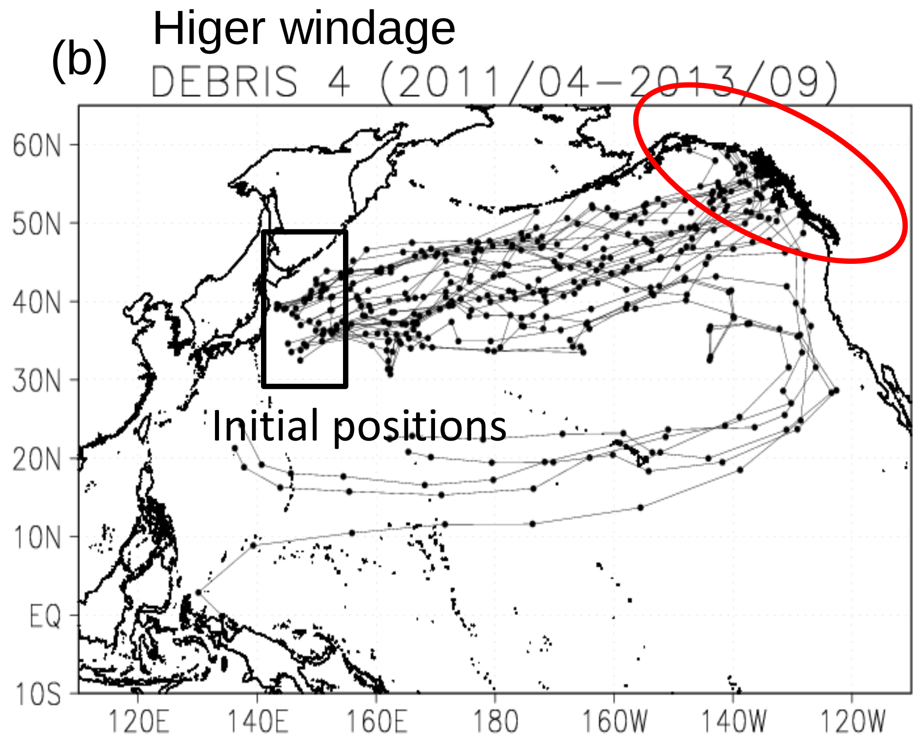


Figure 7. Same as in Figures 5 and 6 but for particle locations in the GNOME model simulations. Colors indicate particle windages according to the color scales of Figs. 5 and 6. High windages are plotted on a top of lower windages.

Typical debris trajectories with windages (a) 2.5% and (b) 5.0% from April 2011 to September, 2013.





Deterministic Trajectory

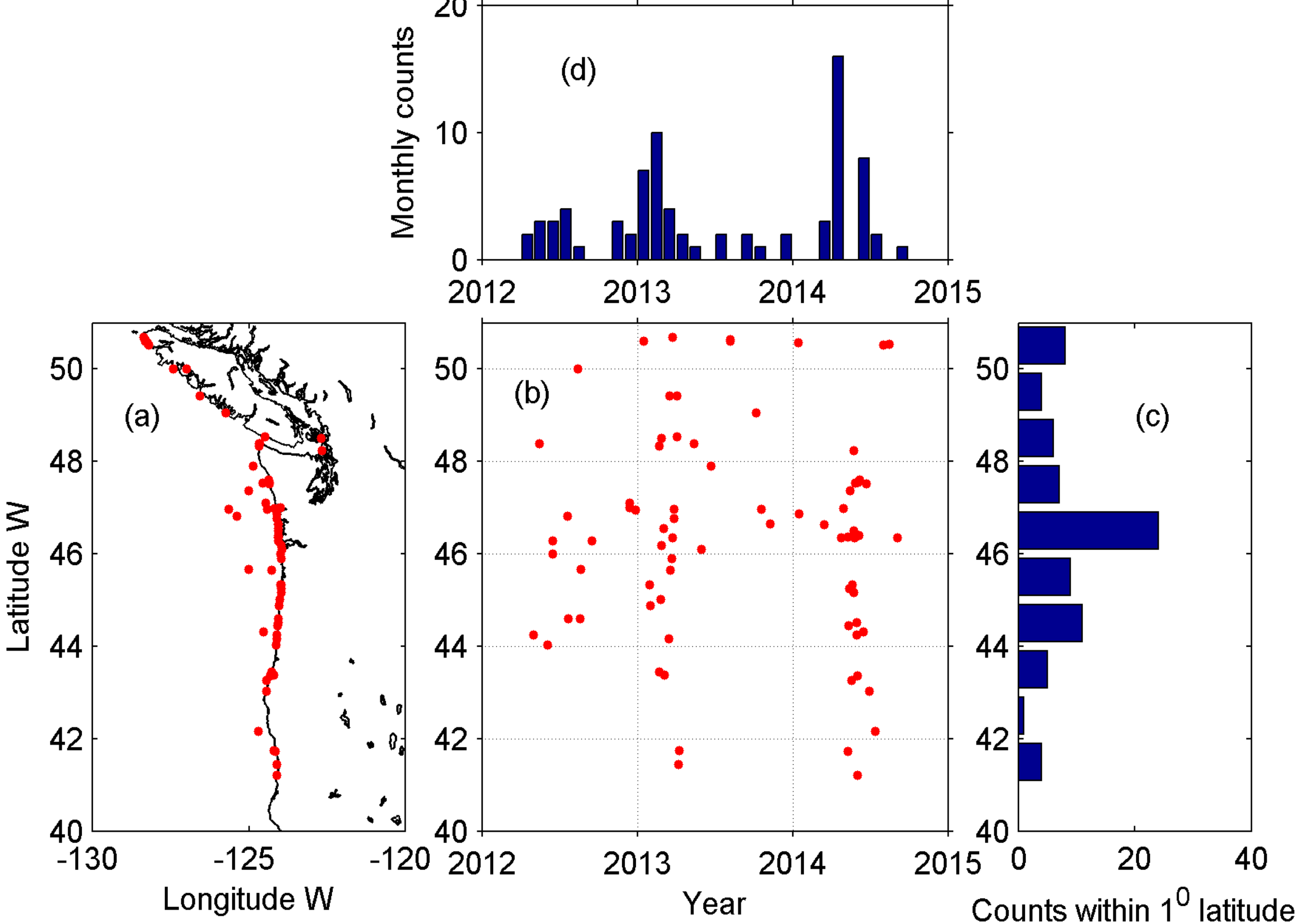


Figure 8. Reports of JTMD boats from the US/Canada coastline between 40 and 51N. (a) Location of reports relative to the shoreline. (b) Latitude-time diagram. (c) Number of reports in 1-degree latitude bins. (d) Monthly number of reports.

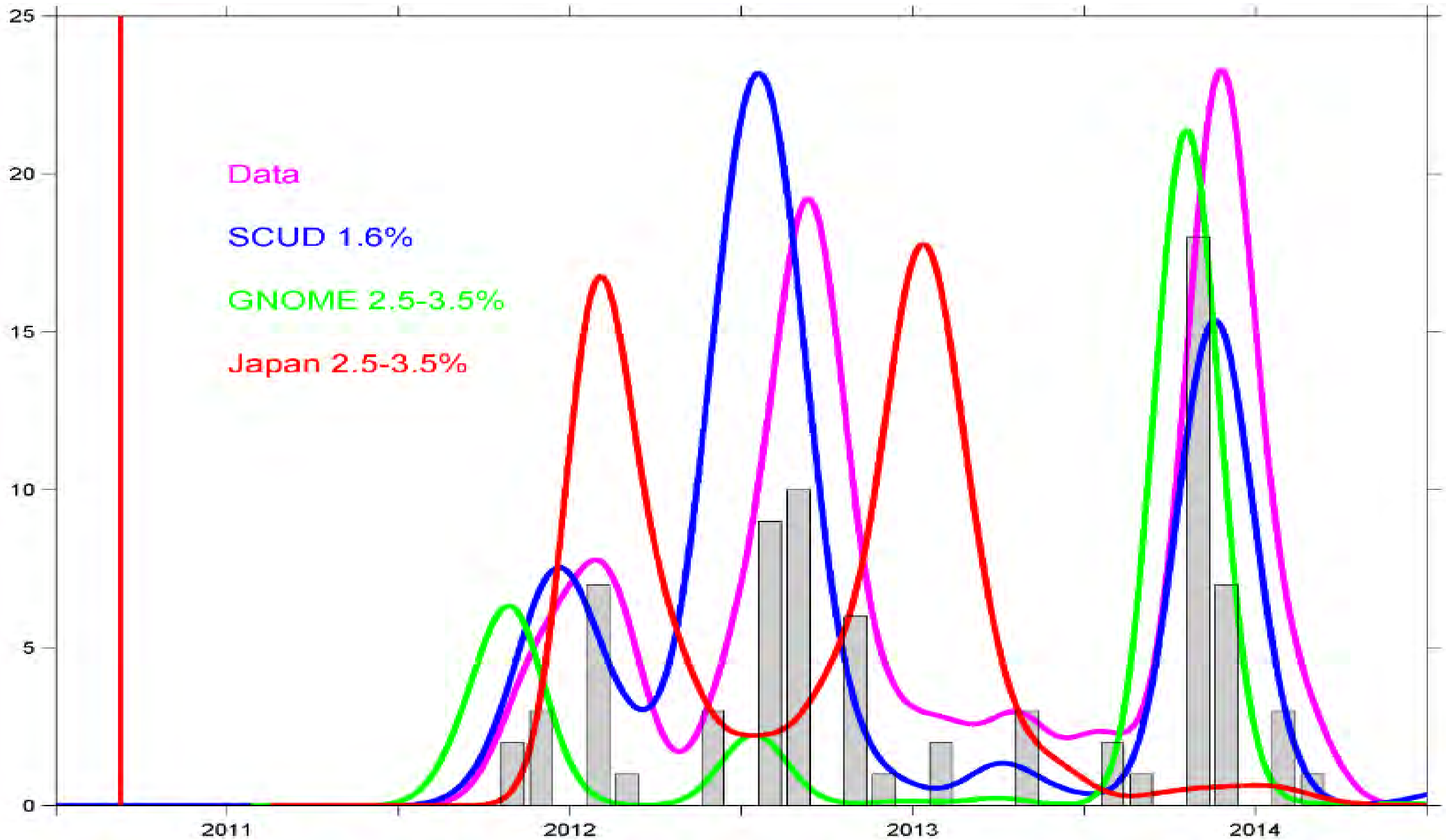


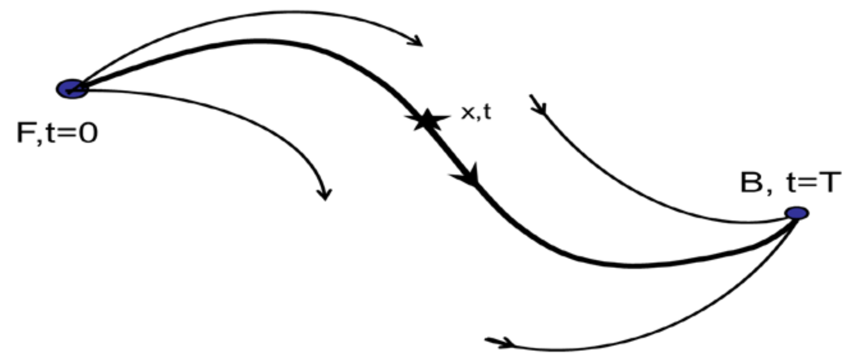
Figure 10. *Monthly counts of boats on the U.S./Canada west coast (gray bars) and low-pass filtered timelines of boat fluxes in observations (magenta) and model experiments with different windages: 1.6% for SCUD (blue) and 2.5–3.5% averages for GNOME (green) and SEA-GEARN/MOVE-K7 (red). Vertical red line marks March 11, 2011. Units on y-axis are boat counts for monthly reports and conventional for other timelines.*

Probabilistic Trajectory

The trajectories as well as distributions of debris have uncertainties, which can be expressed in a probabilistic way. For selected start and destination (or target) points, the uncertainties can be estimated from a combination of trajectories from the starting point forward in time and trajectories from the destination point backward in time in a manner of Fujii et al. (2013).

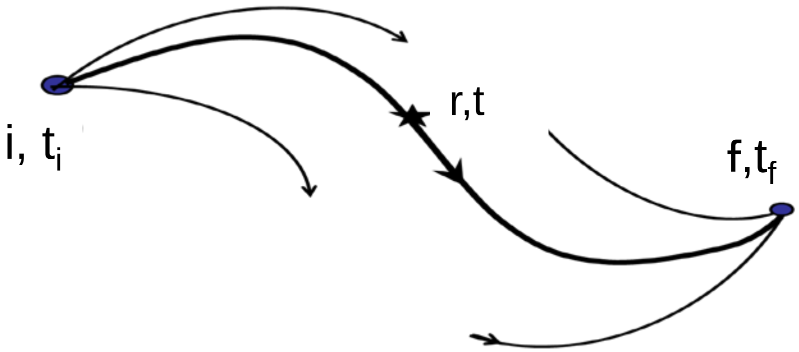
Chapman-Kolmogorov eqn.

$$p(B|F) = \int p(B|x,F)p(x|F)dx$$



Theoretical justification of the method was given in the forward (prediction) and backward (adjoint) models systems which are common in the data assimilation community. Holzer and Primeau (2008) and Fujii et al. (2013) used them to calculate the "path density" in different applications (e.g., water mass movements). In these studies the basic method is according to a balance that the time derivative of forward variable multiplied by its adjoint variable equals with the divergence of terms derived from advection and diffusion. Then the combined (multiplied) variable is conserved, and its distribution gives the probability density. Maximenko et al. (2015b) based their estimates on the interpretation of tracer concentration as a probability density of a single particle motions.

Probabilistic Trajectory: Theoretical Beckground

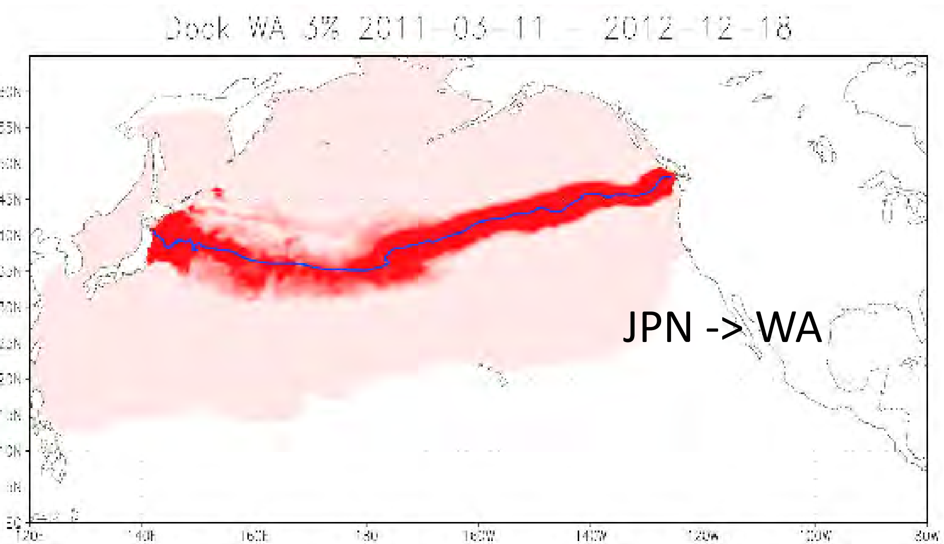


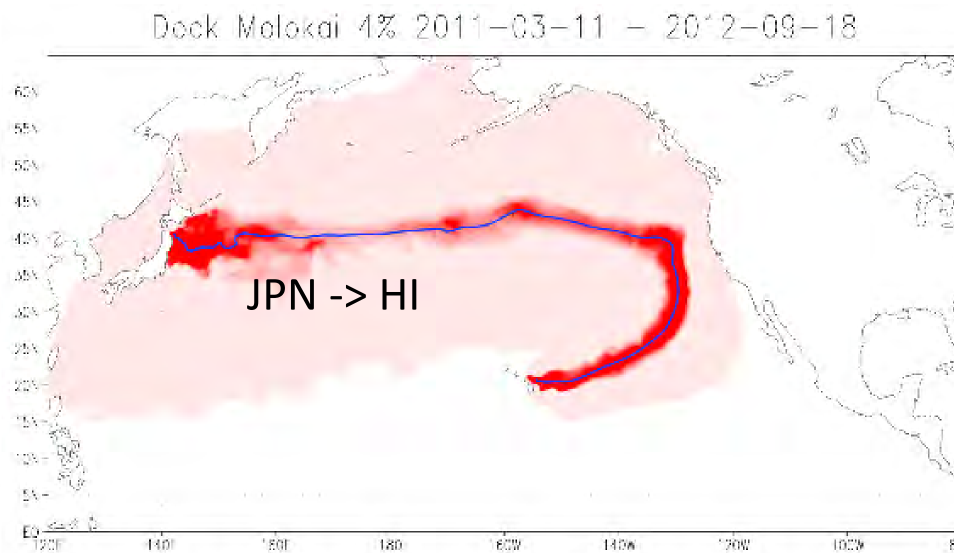
Method (Joint pdf) (Holzer & Primeau, 2008; Fujii et al., 2013)
(forward)x(backward full adjoint)

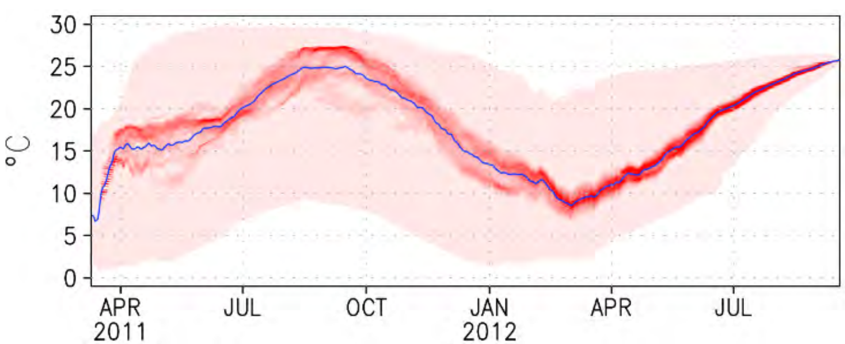
$$\rho\left(\mathbf{r}, \tau, \Omega_i, \Omega_f; t\right) = \frac{\rho(\mathbf{r}, t)}{M} \int_{t-\tau}^{t} dt_i\, \widetilde{\mathcal{G}}(\mathbf{r}, t | \Omega_f, t_i + \tau)\, \mathcal{G}(\mathbf{r}, t | \Omega_i, t_i)$$

$$\mathbf{J}(\mathbf{r}, t | \Omega_i, t_i) \equiv [\rho \mathbf{u} - \rho \mathbf{K} \nabla] \mathcal{G}(\mathbf{r}, t | \Omega_i, t_i)$$

Probabilistic Trajectory







Probability density function of near-seasurface temperature, measured by the Argo network, along the probable path of Molokai dock

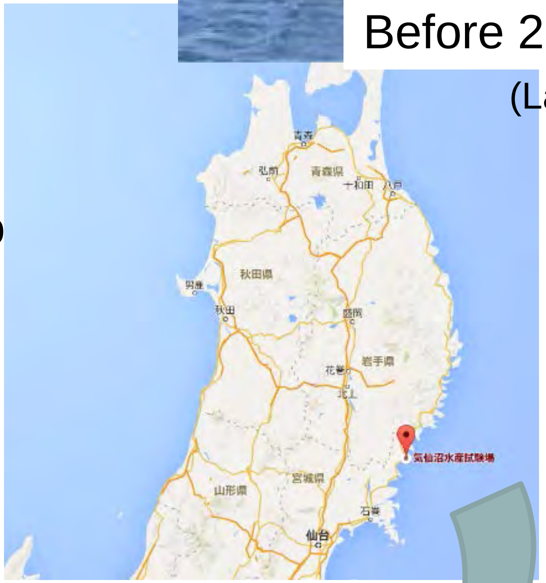
As shown in the figure (Maximenko et al., 2015b, and also Maximenko and Hafner, 2010), such approach gives not only the uncertainty of the trajectoriy of debris but also probabilistic information of the sea environment (e.g., temperature) along the trajectory and time. This information is critical for detecting probable path of invasive species colonizing debris items.

Example (Request)

Research Vessel (Kaisyou, 1.1ton) of Kesennuma Local Fisheries Laboratory (Miyagi prefectural Government) was found at about 6km offshore area from Miyako-city, Okinawa prefecture in May 12, 2016.

The prefectural government group would like to know the route.

Before 2011



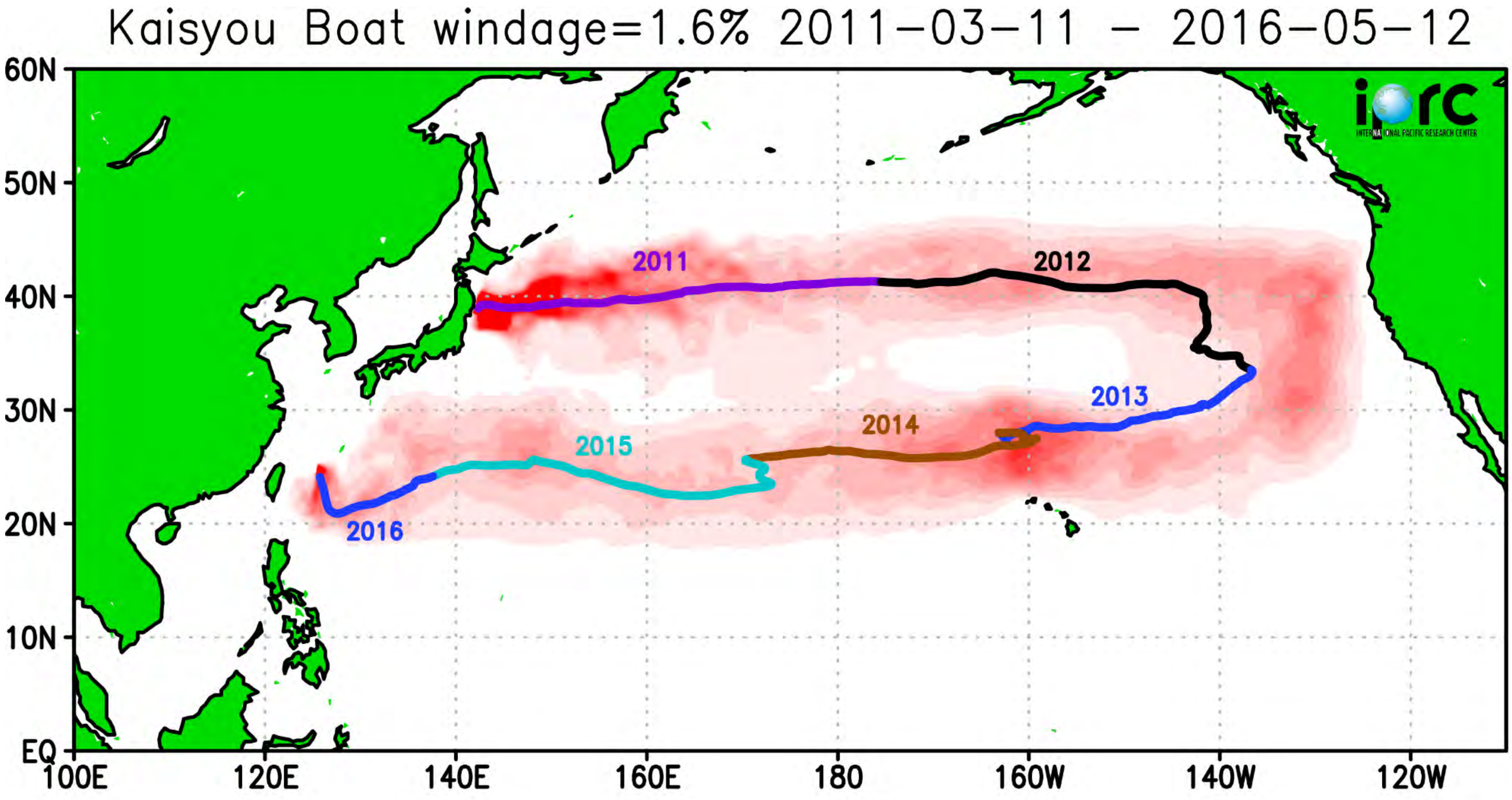
(Lat=38.8, Lon=141.6

(Lat=24.7, Lon=125.3)

After found in 2016/5/12

?

Example (Answer)
Probabilistic route



Summary (some figures are not shown)

1. High computing simulation and data assimilation are useful for the calculation of marine debris distribution. The model solution depends on the windage. 海上と海中の割合が重要
2. On-shore observation and model solution estimated seasonal change: e.g., summer 2012, winter-spring 2013, spring-summer 2014, due to seasonal wind and ocean current fields. 季節的な変動
3. Model solution estimates that less than 10% of the tracer washes ashore annually and suggests that more than 50% of JTMD with boat type windage was still floating in the end of 2016. This means that boats from the 2011 tsunami, built to withstand rough ocean conditions, will likely continue coming to the US/Canada coastline in several future years. At the same time, JTMD wandering in the gyre gradually mixes with marine debris from other sources and loses its identity. まだ半分程度は漂っていそう
4. Future progress in marine debris modeling requires radically improved at-sea and on-shore observing systems as well as better model descriptions of coastal process and processes on the sea surface (such as Stokes drift by wind waves) and their effects on floating objects. より細かい沿岸モデルが必要

Thank you for your attention