Numerical simulations on the transport and dispersion of ^{137}Cs in the upper ocean due to the Fukushima disaster

Chang Zhao, Fangli Qiao*, Guansuo Wang, Changshui Xia

The First Institute of Oceanography, SOA, China

KyungTae Jung

Korea Institute of Ocean Science and Technology, Korea

Oct.15th, 2015, Qingdao, China

*Corresponding Author:
Fangli Qiao, Email: qiaofl@fio.org.cn

Outline

1 Introduction

2 Model description and Method

3 Surface spreading of the Fukushima-derived cesium

4 Southward(Vertical) spreading of the Fukushima-derived cesium

5 Conclusions

Outline

1 Introduction

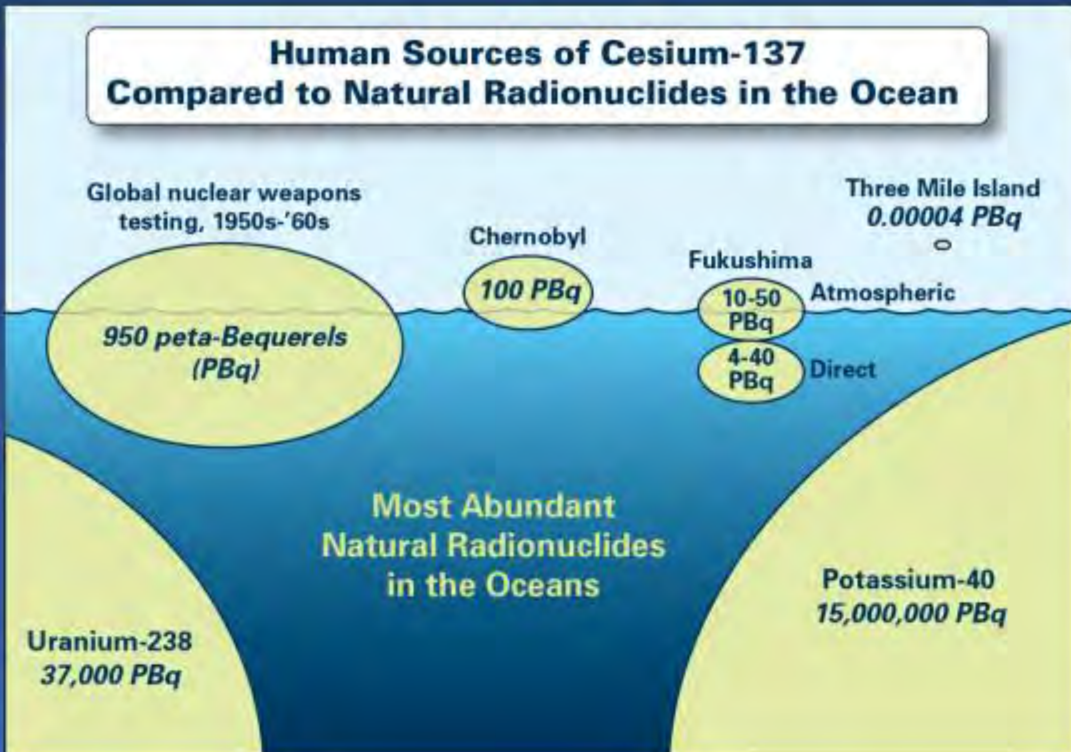
2 Model description and Method

3 Surface spreading of the Fukushima-derived cesium

4 Southward(Vertical) spreading of the Fukushima-derived cesium

5 Conclusions

We live in a radioactive world (and ocean)



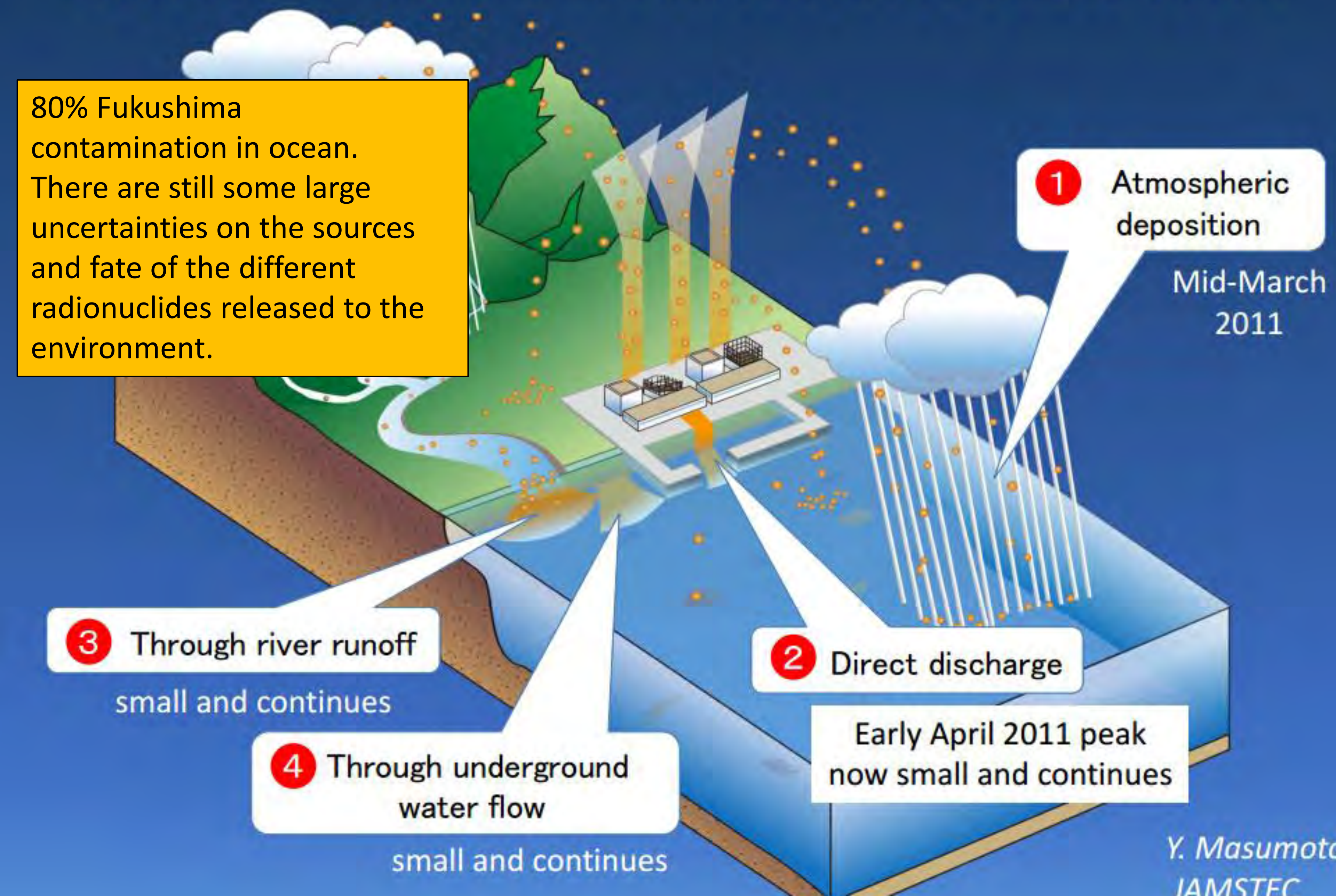
1 Bq = 1 Becquerel = one radioactive decay per second
1 PBq = peta-Becquerel = one million billion Bq
10^{15} Bq = 1,000,000,000,000,000 Bq

- Natural sources are larger than man-made sources
- Fukushima total still poorly known
- We can measure less than 1 Bq
- In the ocean (and human body) different radionuclides have different fate and toxicity
- Cesium is soluble in seawater
- ^{137}Cs half-life = 30 years
  ^{134}Cs half-life = 2 years

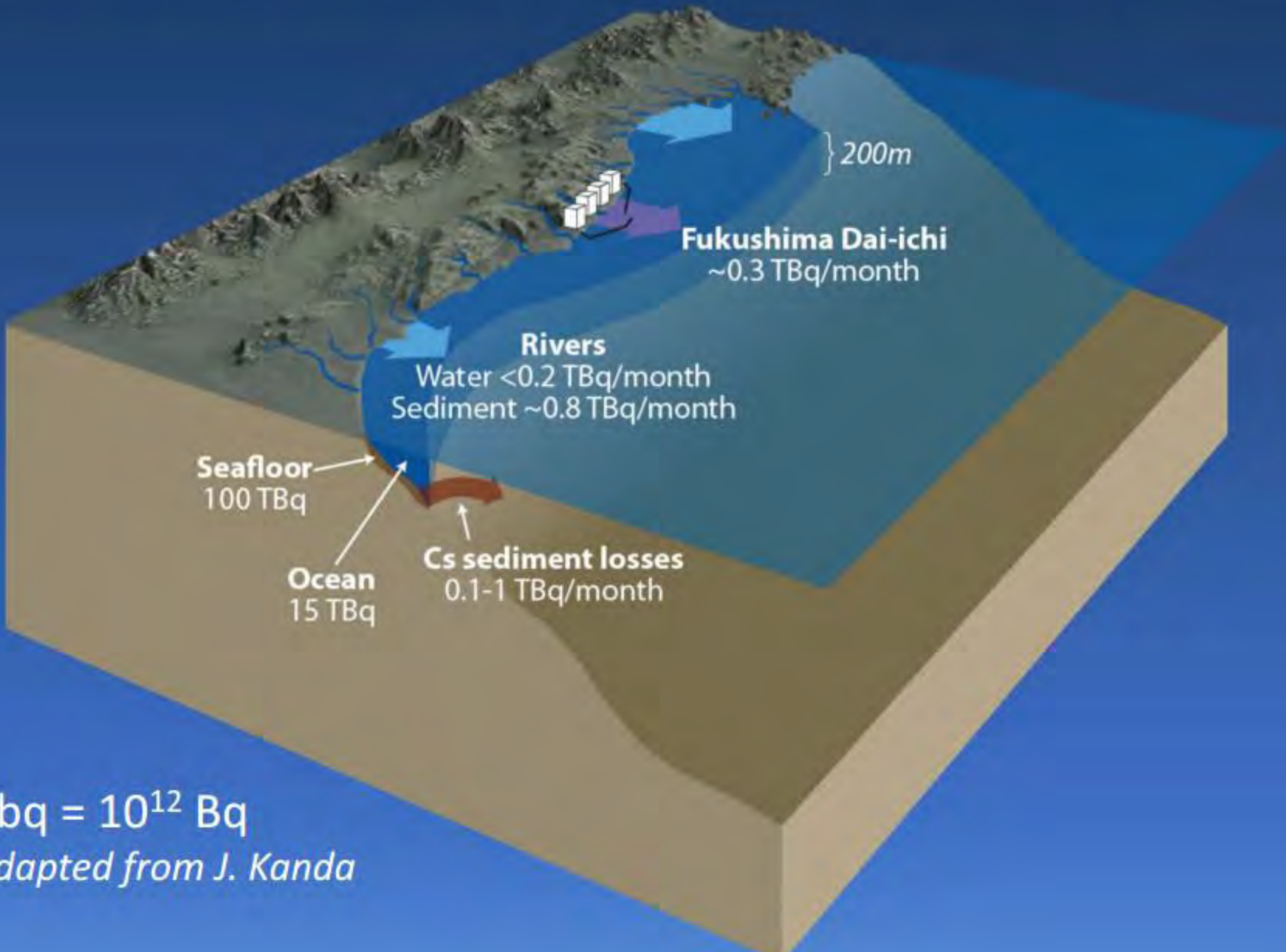
Ken Buesseler
WHOI

Sources of Fukushima radionuclides to the ocean

80% Fukushima contamination in ocean. There are still some large uncertainties on the sources and fate of the different radionuclides released to the environment.



What are cesium-137 sources and sinks today?



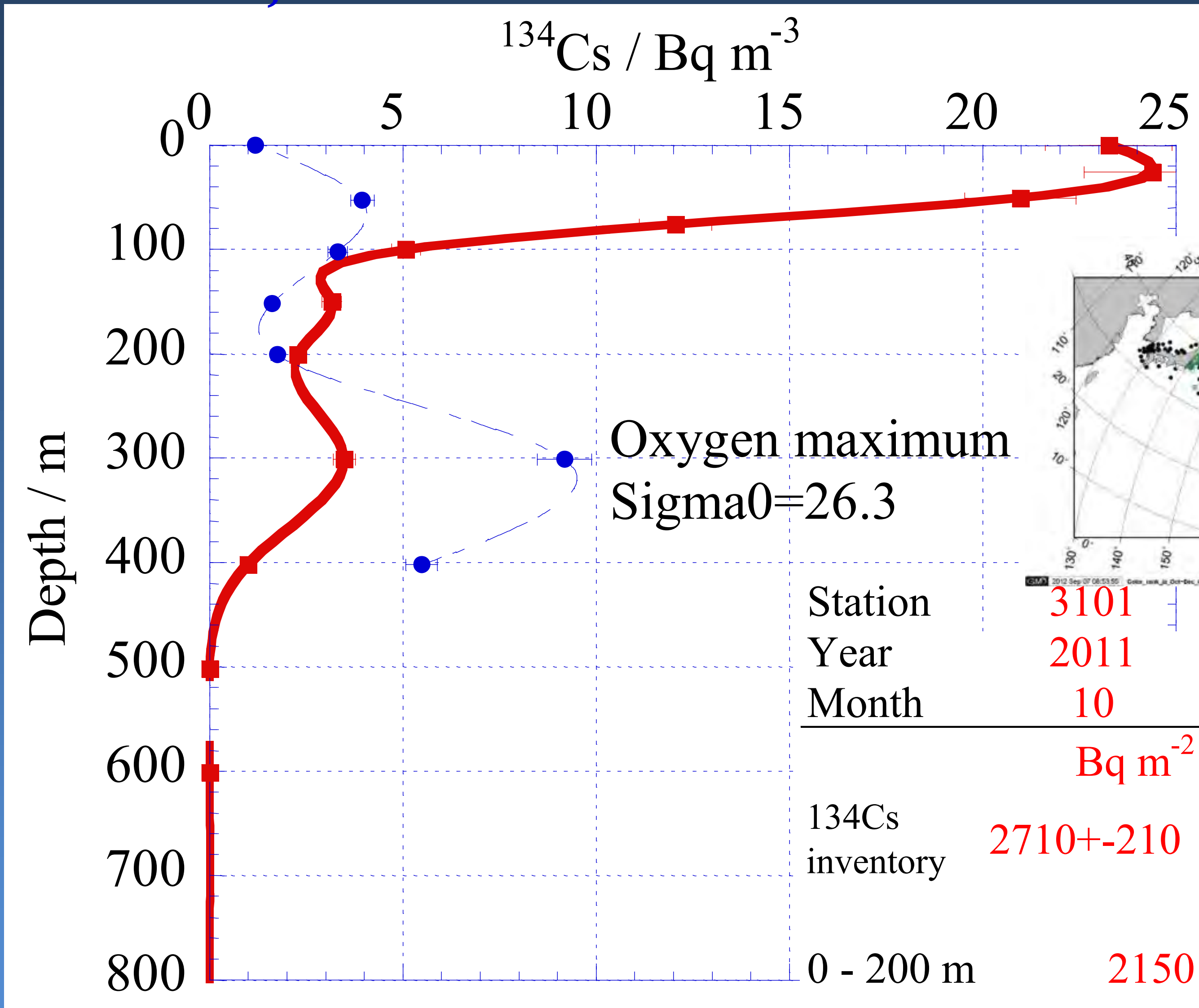
Tbq = 10^{12} Bq

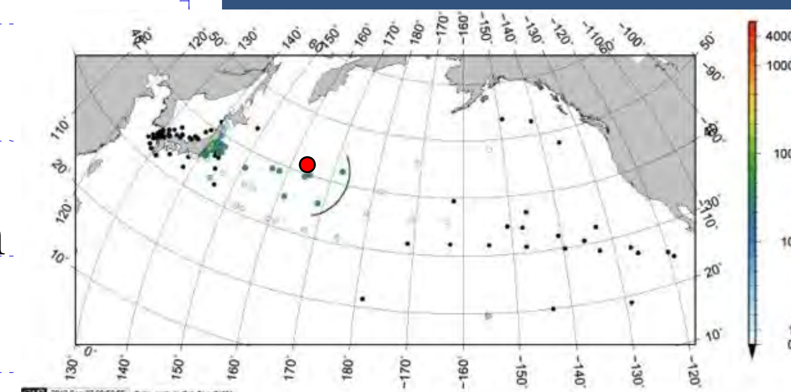
adapted from J. Kanda

Over time, Cs moves east and mixes deeper in ocean

and

at 39N, 165E on 11 June 2012 stn RF1205-4418





Station	3101	4418
Year	2011	2012
Month	10	6
	Bq m^{-2}	Bq m^{-2}
134Cs inventory	2710+-210	2350+-190
0 - 200 m	2150	520
Deeper than 200 m	520	1830

Outline

1 Introduction

2 Model description and Method

3 Surface spreading of the Fukushima-derived cesium

4 Southward(Vertical) spreading of the Fukushima-derived cesium

5 Conclusions

Model description

(1) How many ^{137}Cs from Fukushima Nuclear Accident into the ocean

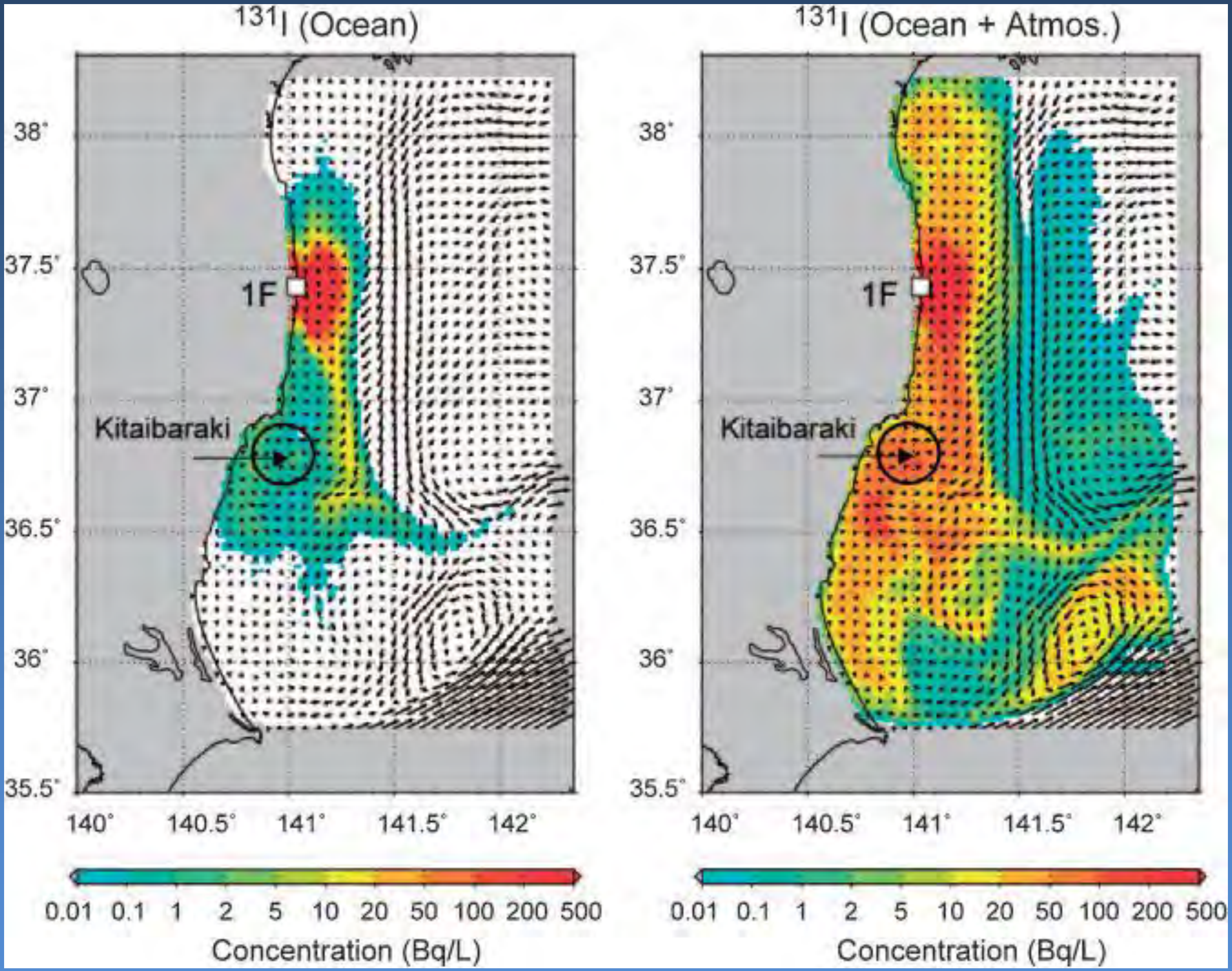
Tokyo Electric Power Company (TEPCO)

Kawamura 2011

Estournel 2012

Time series of the ECMWF wind in the vicinity of the Fukushima power plant.

Model description



Kawamura 2011

As for ^{137}Cs, the amounts deposited into the sea surface was estimated to be 5 PBq.

Model description

(2) Experiment description

Ocean General Circulation Model (OGCM)

1） The circulation ocean model is based on POM.

2） The model domain, 75ºS-65ºN, 0º-360ºE.

3） Horizontal resolution, 0.5º×0.5º.

4） Vertical sigma layers, 21.

5） The model topography is interpolated from the global 5′ by 5′ ETOPO5 dataset.

6） The circulation model is driven by monthly climatological (COADS) wind stresses and heat fluxes.

7） The initial temperature and salinity field are set to the Levitus annually averaged temperature and salinity, and the initial velocity is set as 0.

8） Spin up 20-year.

Model description

Calculation of radionuclides concentrations in the ocean

$$\frac{\partial C_{\mathrm{d}}}{\partial t} = (adv + dif) - \lambda C_{\mathrm{d}} - K_d \rho_s(z) w_s \frac{\partial C_d}{\partial z}$$

C_d is the radionuclide concentration (Bq/m^3)

λ is the decay constant of the nuclides s^{-1},

K_d The distribution coefficient （m^3/g）

137-Cs: K_d=2.0*10^{-3}

$\rho_s(z)$ isthe concentration of the suspended materials kg/m^3

$\rho_s(0)$=0.25g/m^3

$$\rho_s(z) = \rho_s(0) \times 10^{-0.0005z}$$

w_s is the settling velocity of suspended materials m/s

w_s =100m/day.

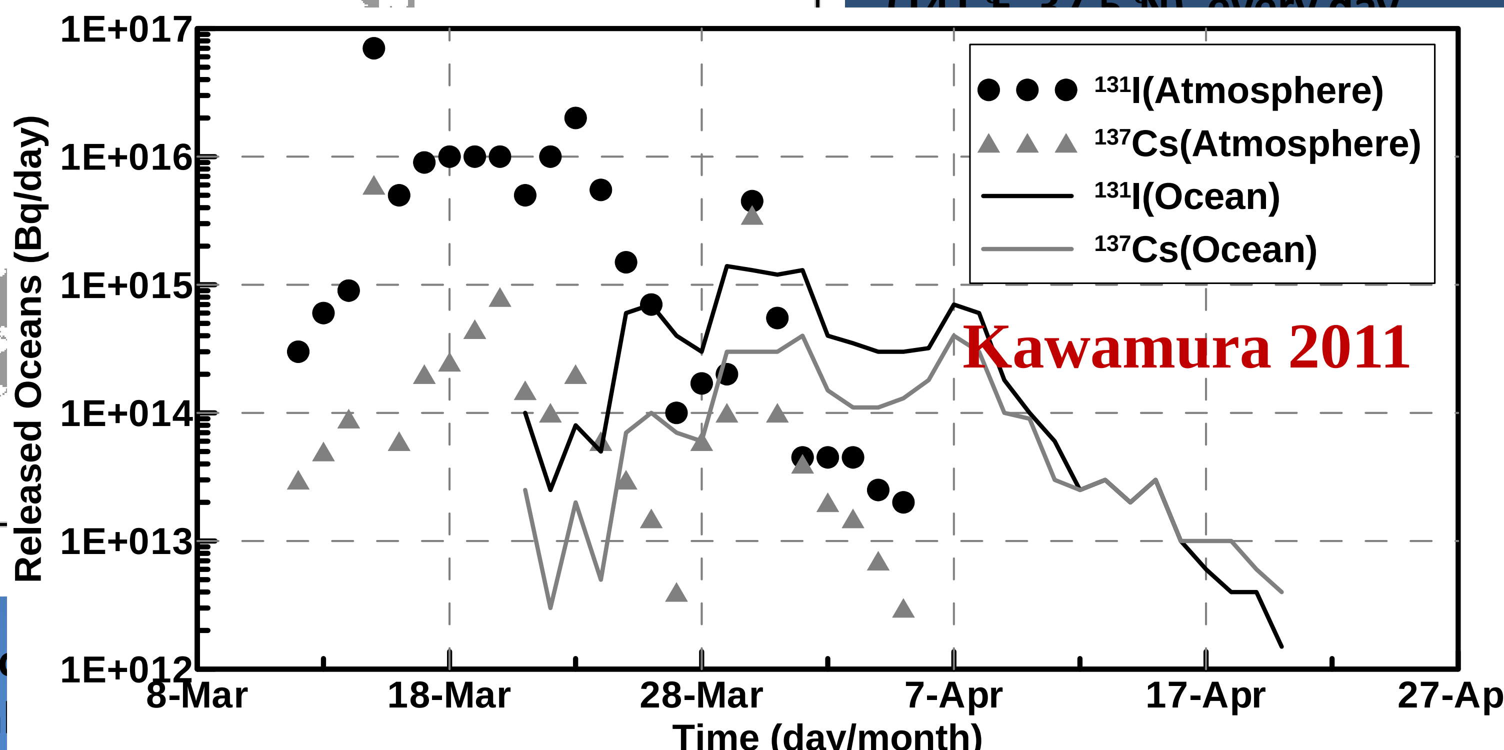
$adv + dif$ Radionuclide concentration convection-diffusion

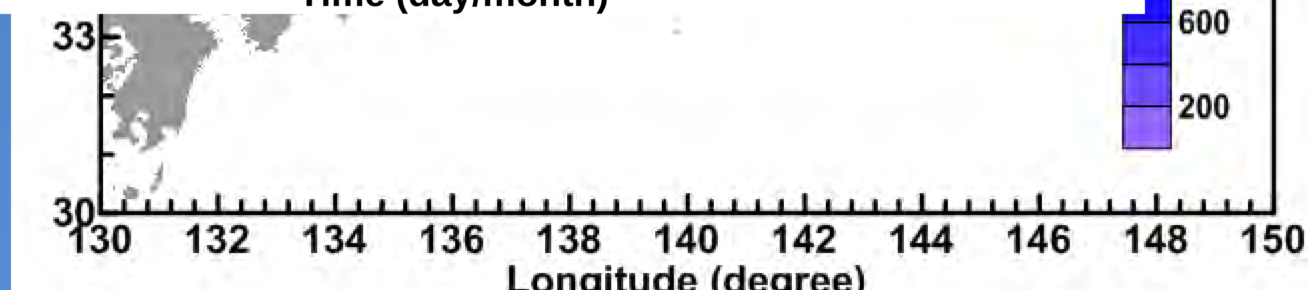
Daisuke Tsumune, 2003. Numerical simulation of ^{137}Cs and ^{239,240}Pu concentrations by an ocean general circulation model. Journal of Environmental Radioactivity 69: 61–84

(3) ^{137}Cs Boundary Conditions

Model description

In the first layer, Direct release 137-Cs at Fukushima Daiichi (141 °E, 37.5 °N) every day



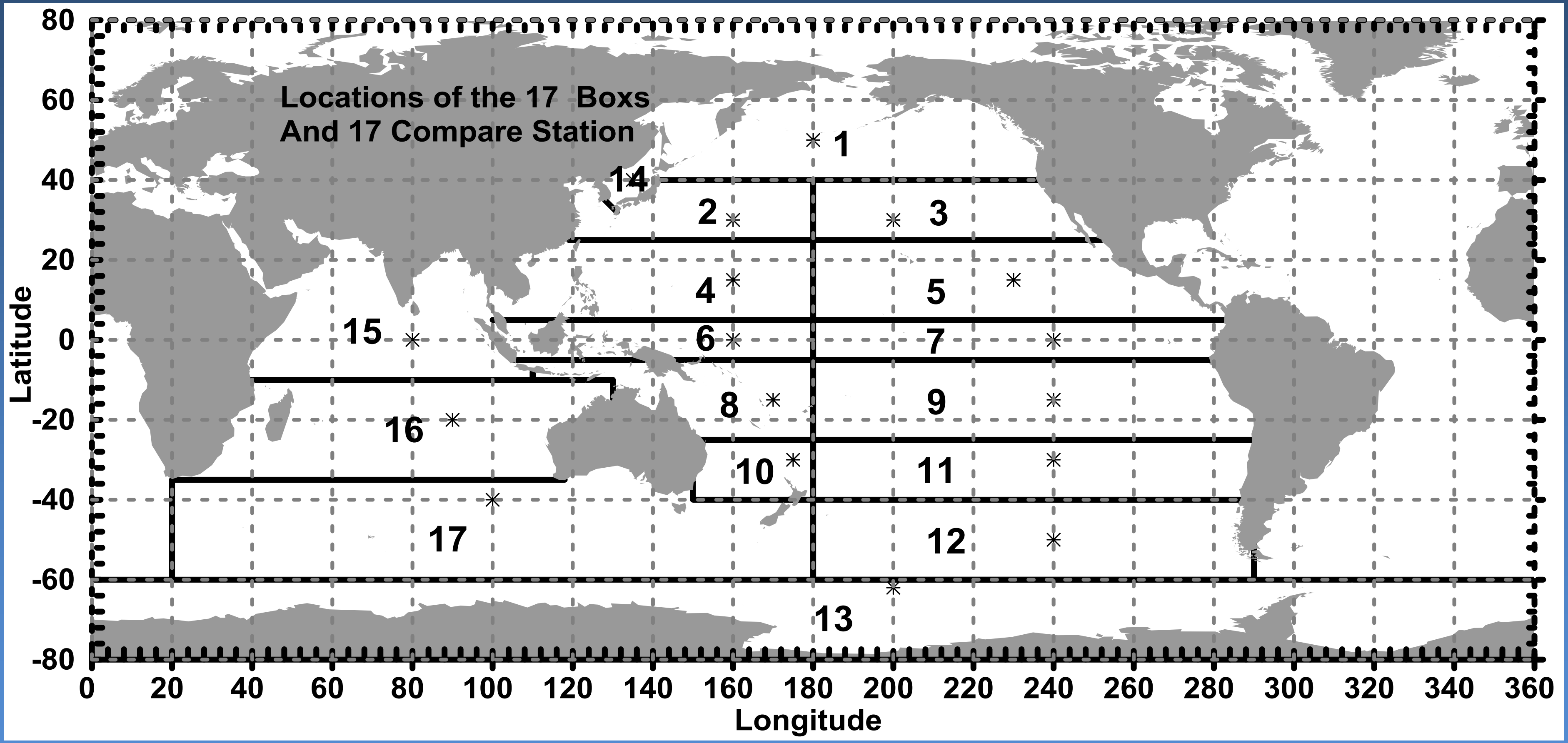


The surfac
horizontal
distribution of ^{137}Cs
concentrations on
April 22th, 2011.

Model validation

Model result

Validation Surface Chronological distribution of ^{137}Cs

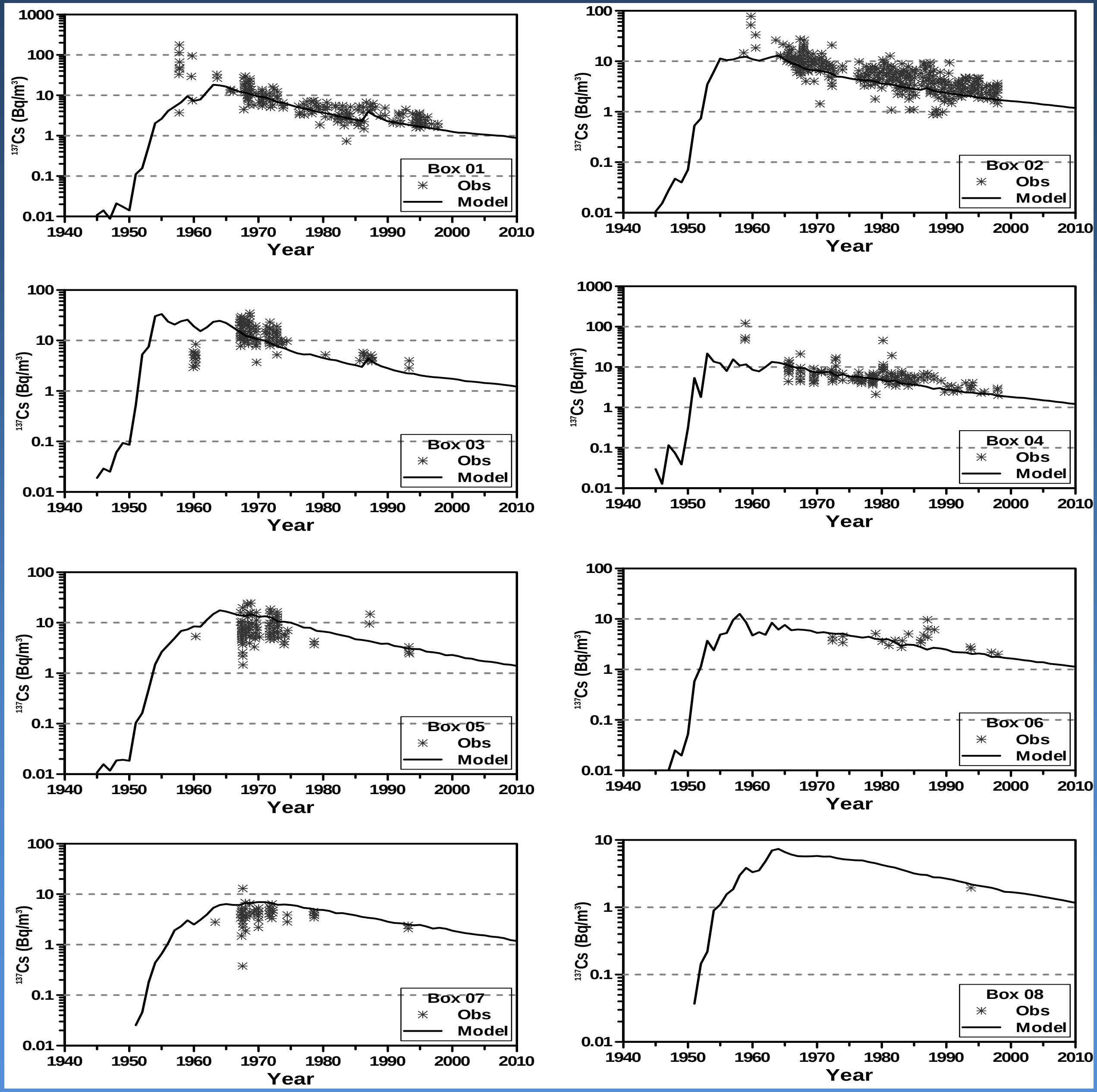


*** Model Station**

Povinec (2005)

Model validation

Validation Surface Chronological distribution of ^{137}Cs

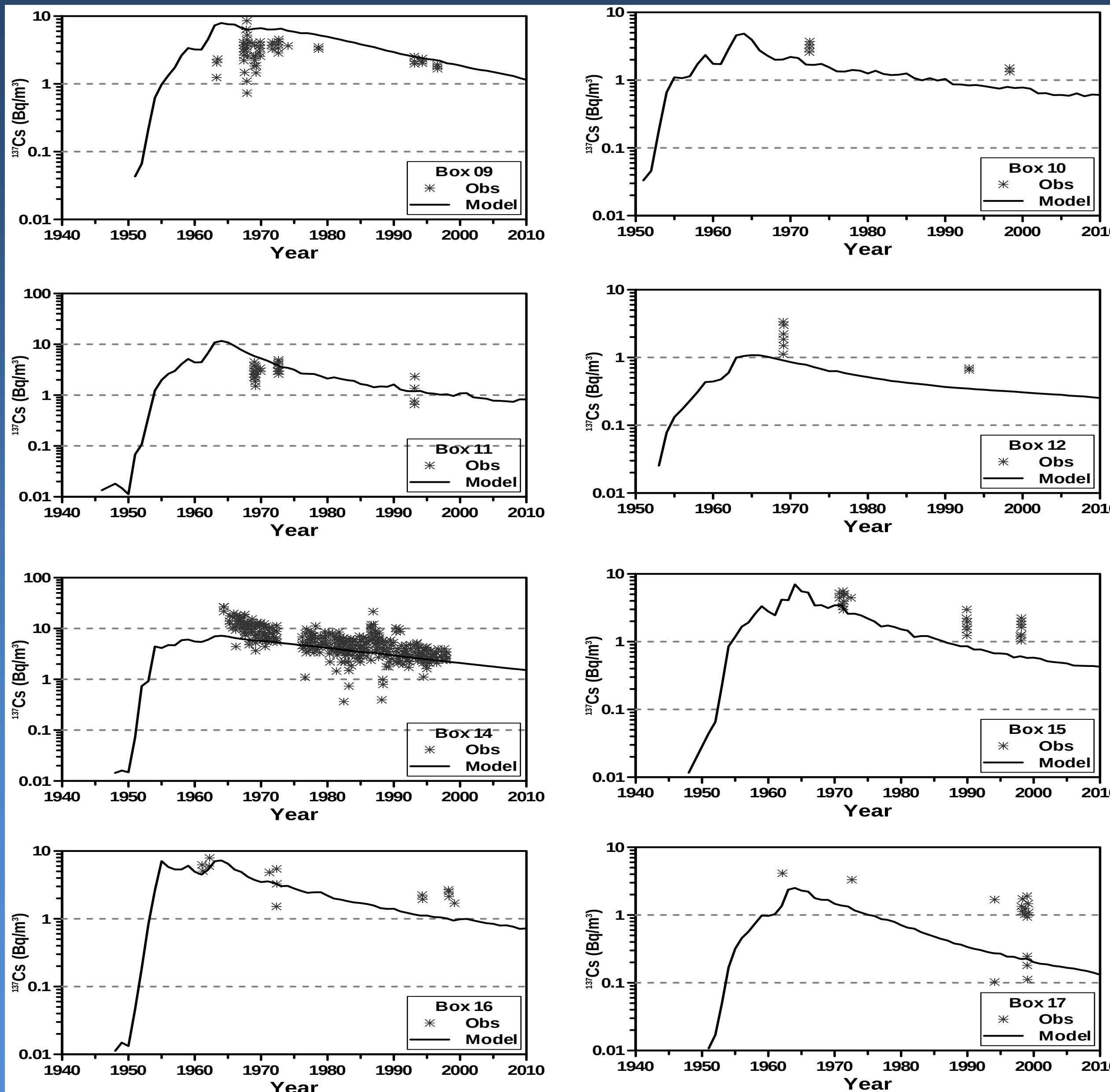


Observation: Povinec (2005)

Model validation

Model result

Validation Surface Chronological distribution of ^{137}Cs

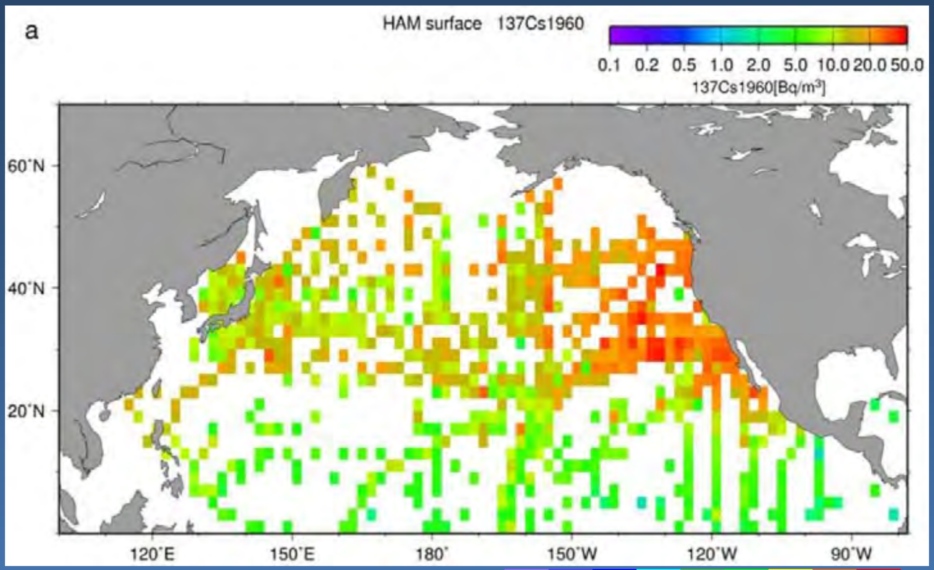


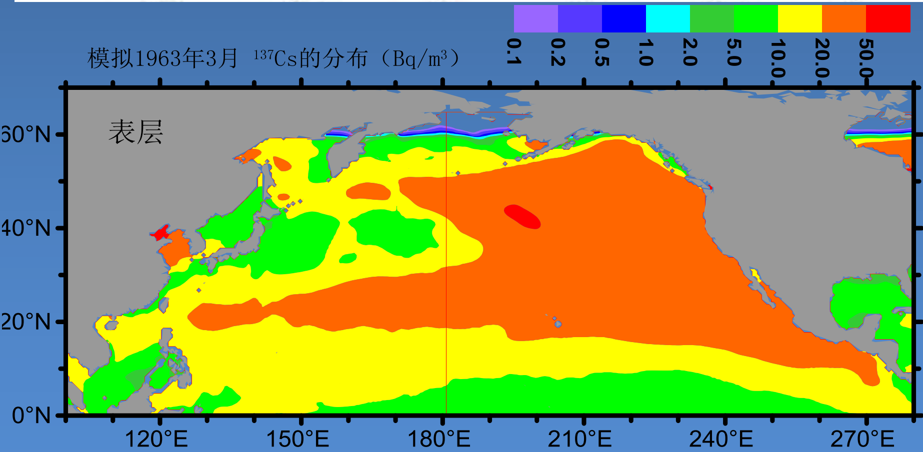
Observation:
Povinec (2005)

(1) Model validation

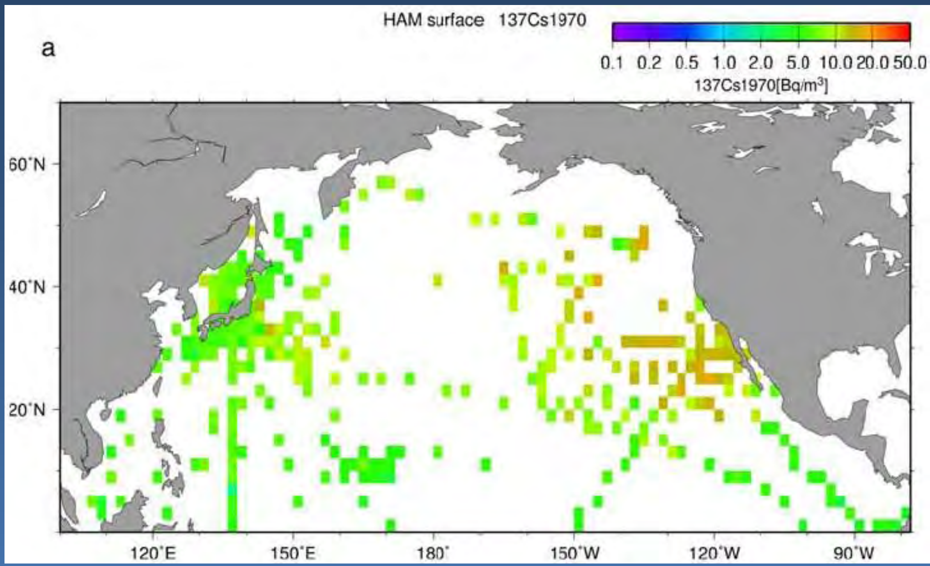
Model result

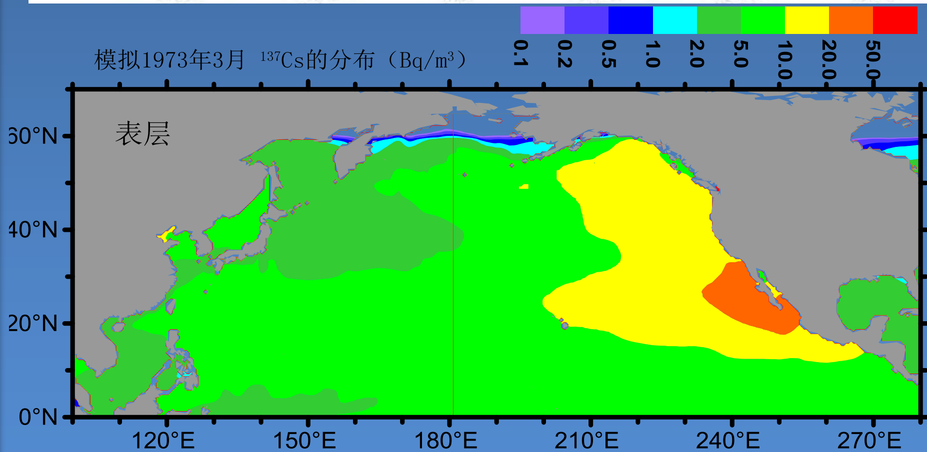
Surface observation time: 1960s; 1970s





In the 1960 s
The figure above: HAM Observation
The figure below: Model





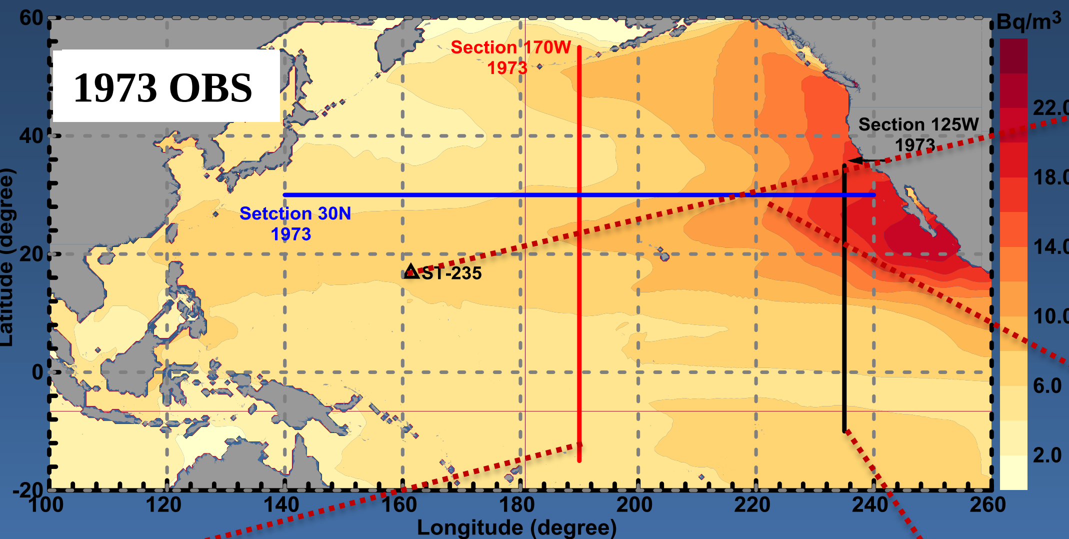
In the 1970 s
The figure above: HAM Observation
The figure below: Model

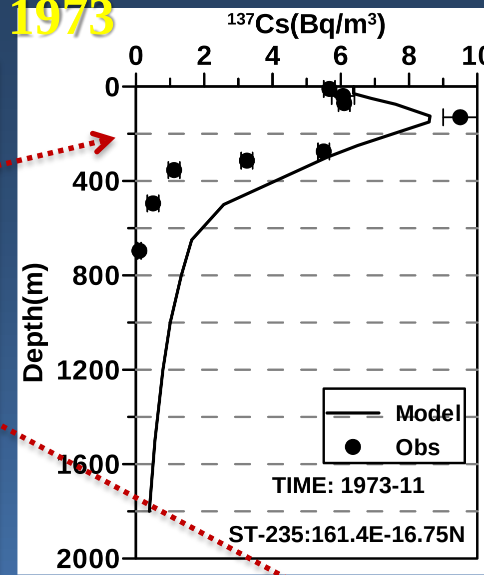
Observation: Tsumune （2003）

(1) Model validation

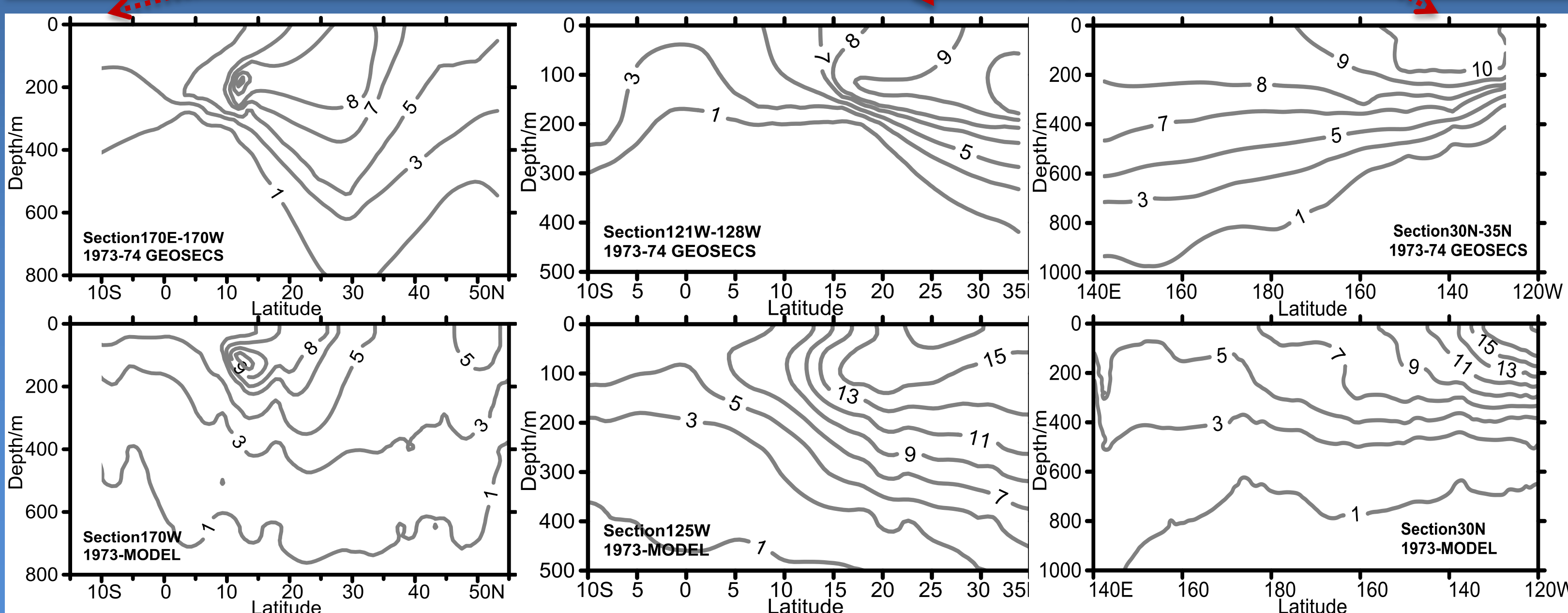
Model result

North Pacific Observation time: 1973





ST-235
1973
November



Above：Observation
Below：Model

30N

170W

125W

Observation: Bowen （1980）

Outline

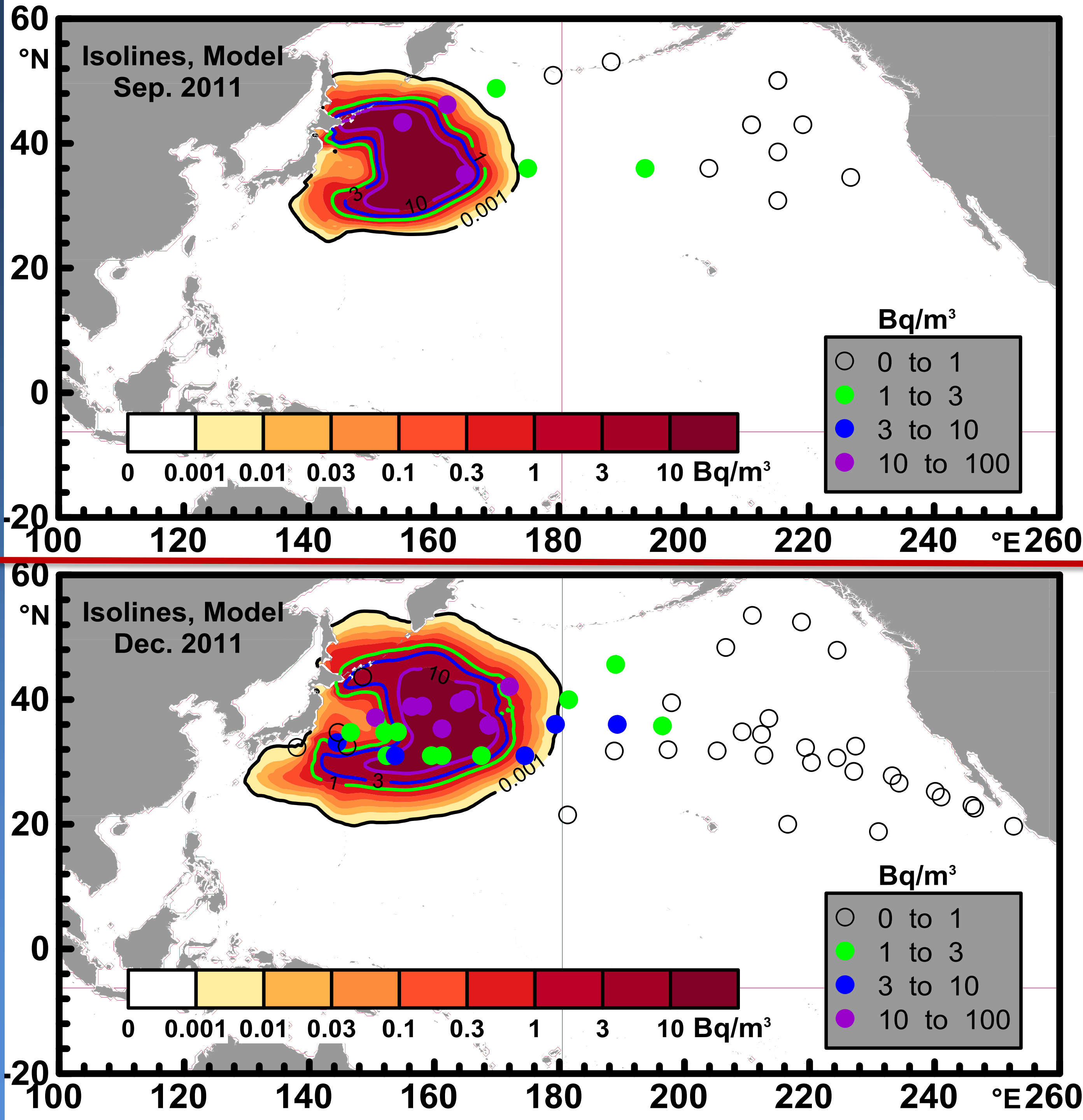
1 Introduction

2 Model description and Method

3 Surface spreading of the Fukushima-derived cesium

4 Southward(Vertical) spreading of the Fukushima-derived cesium

5 Conclusions



Model result

Model：2011 09

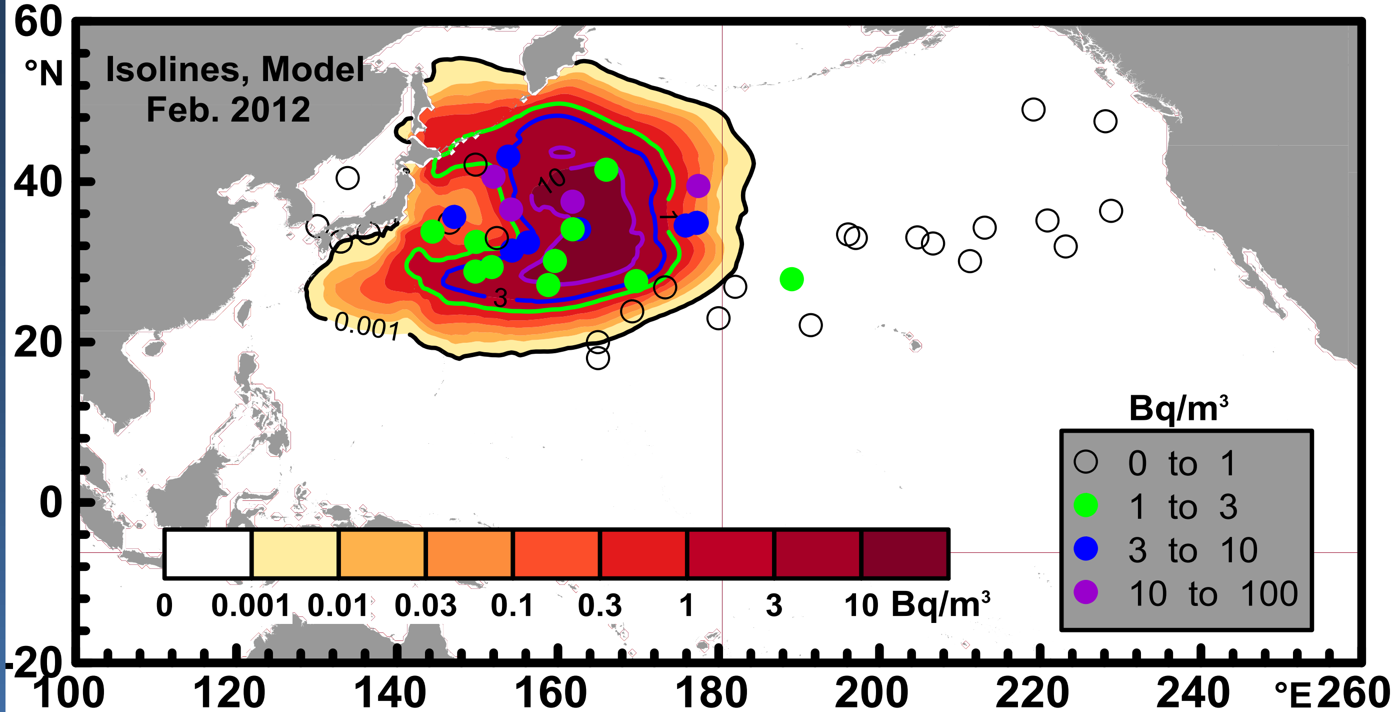
OBS：2011 08-09

Model：2011 12

OBS：2011 10-12

OBS data from Aoyama 2013 Biogeosciences

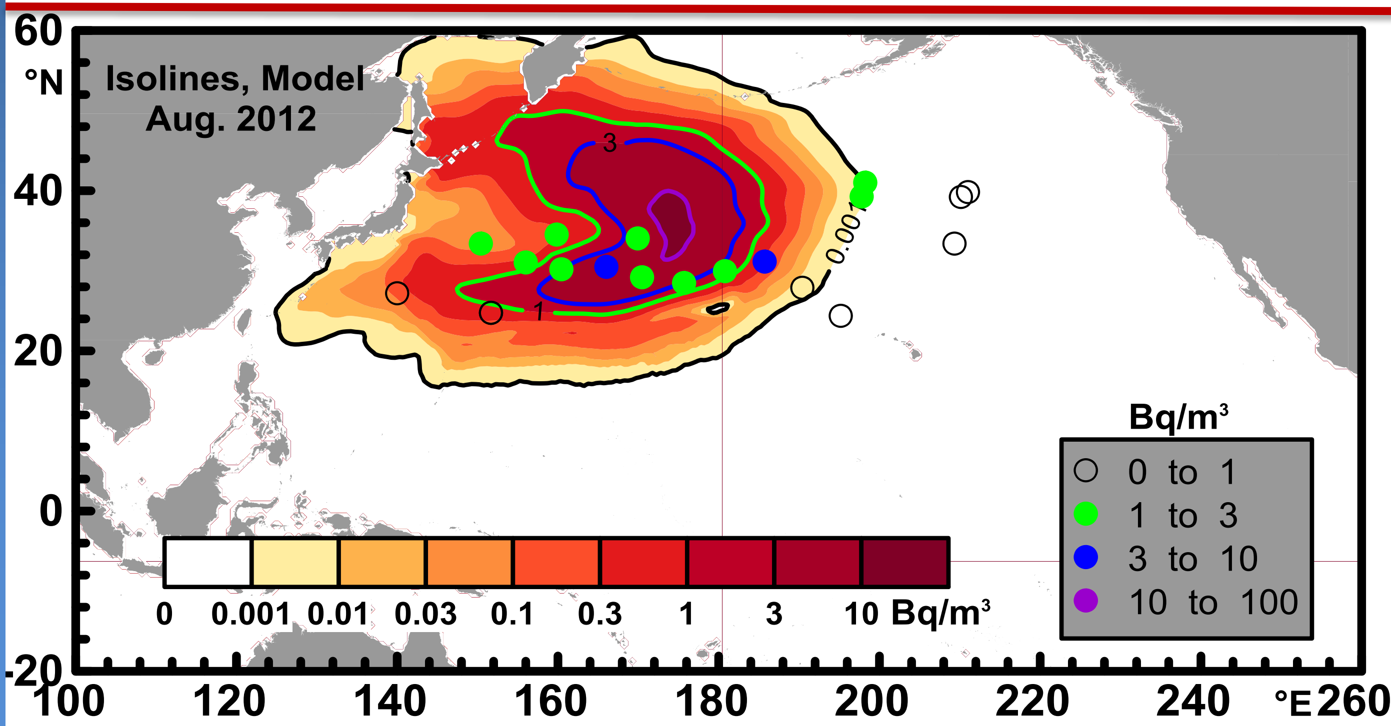
Model result



Model: 2012 03

OBS: 2012 01-03

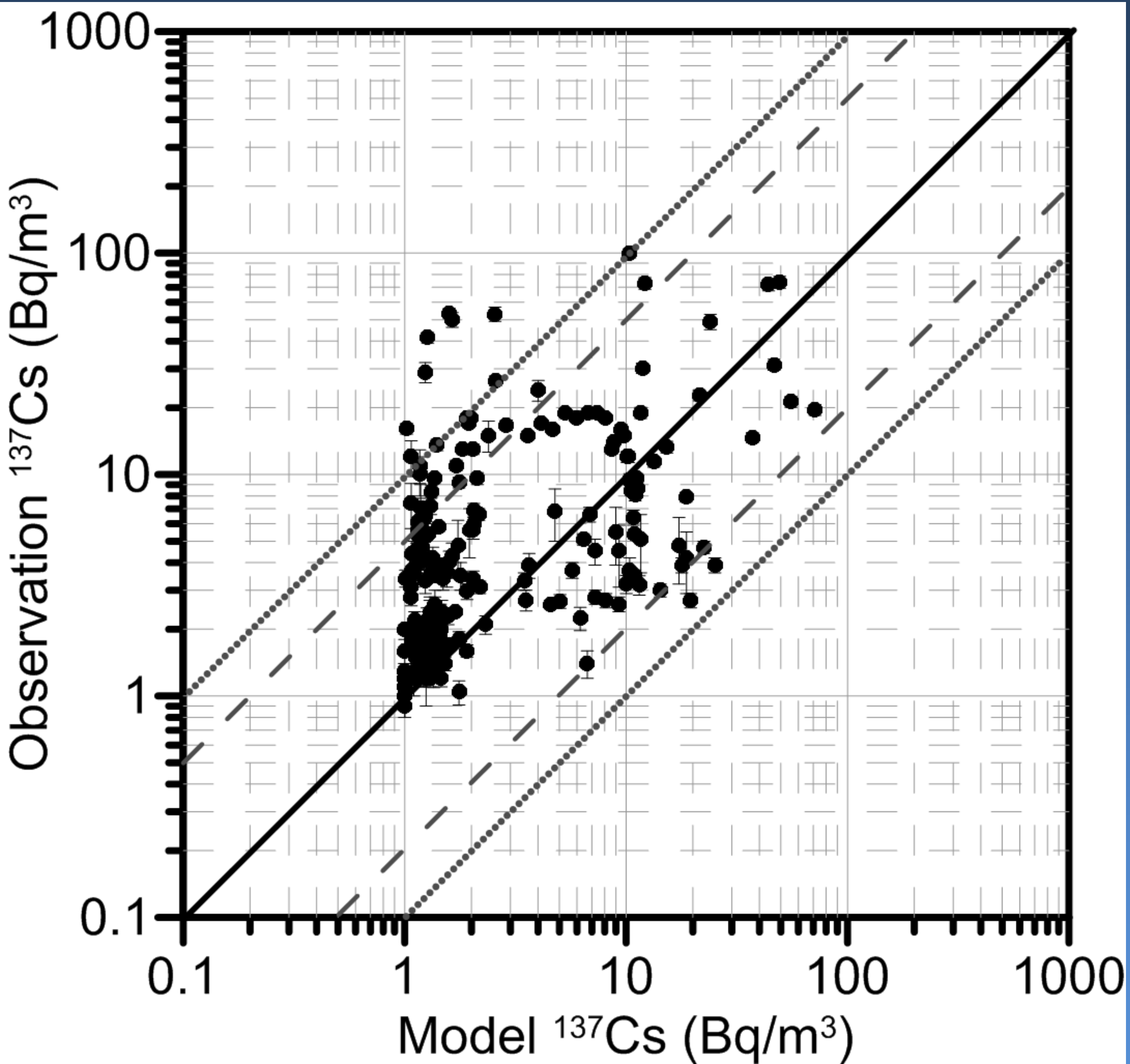
OBS data from Aoyama 2013 Biogeosciences



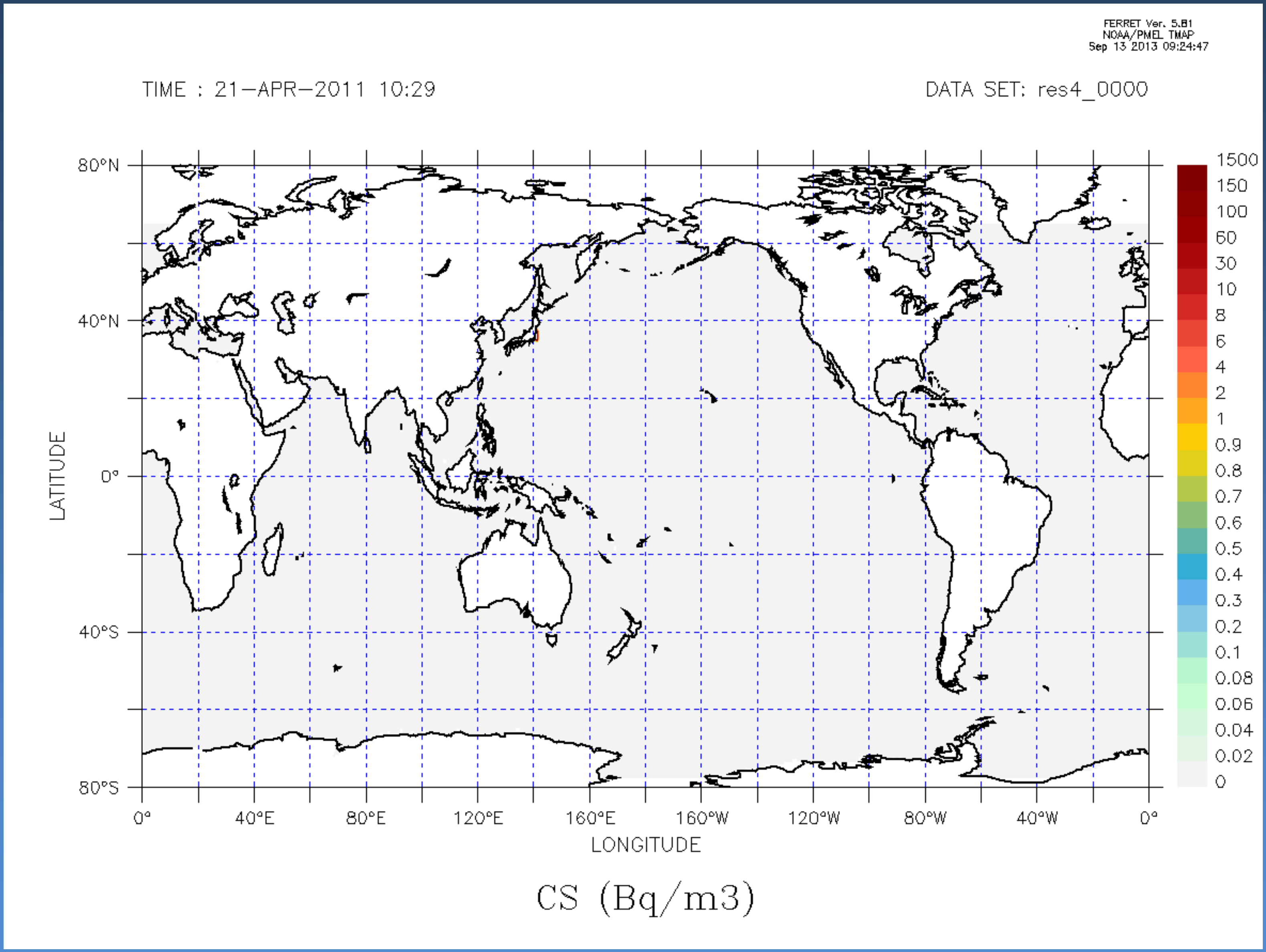
Model: 2012 08

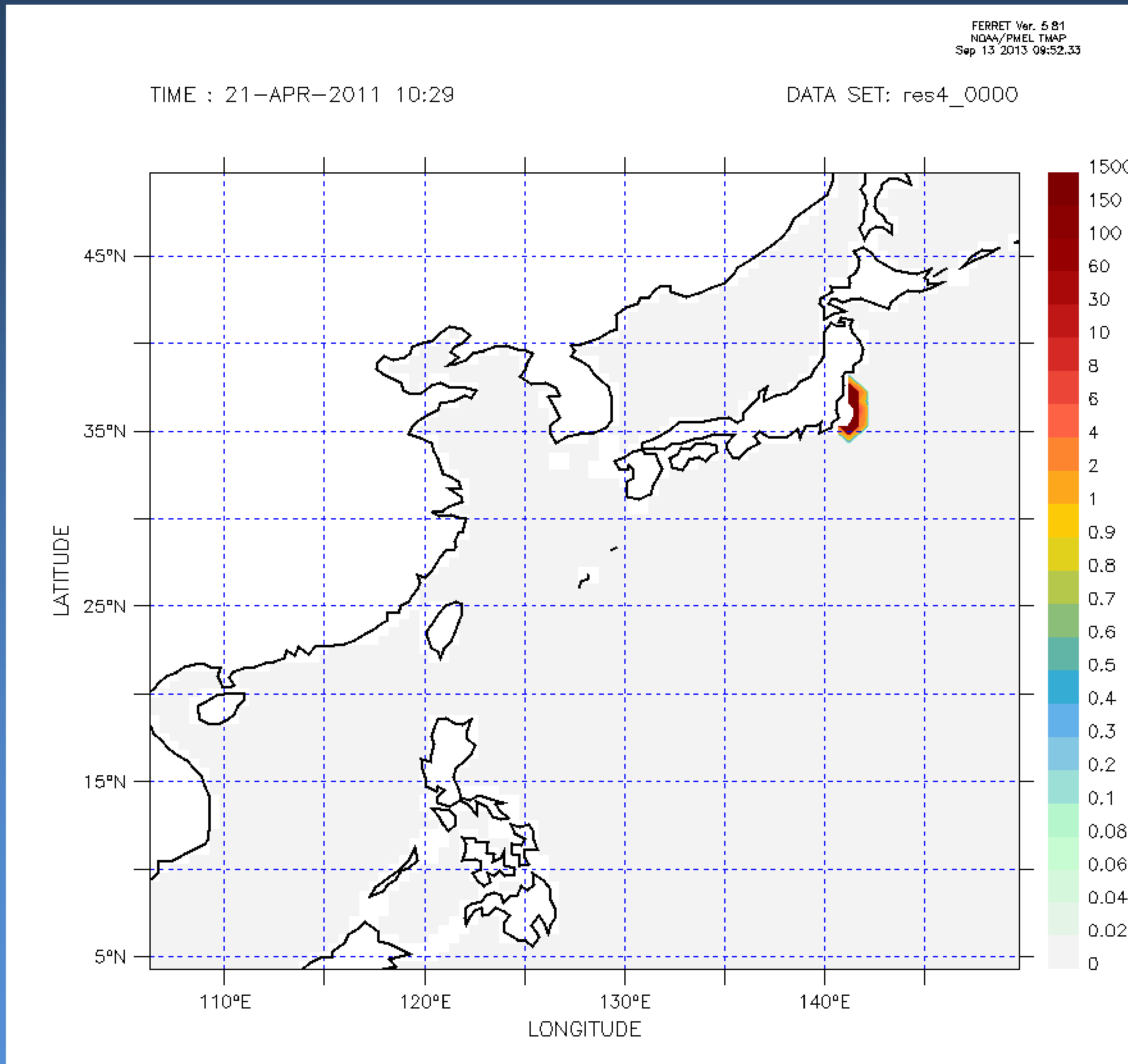
OBS: 2012 07-09

OBS data from Kameník 2013 Biogeosciences



The factors of 5 and 10 are 86.2% and 96.5%, respectively


FERRET Ver. 5.81
NOAA/PMEL TMAP
Sep 13 2013 09:24:47
TIME : 21-APR-2011 10:29
DATA SET: res4_0000
80°N
40°N
0°
40°S
80°S
LATITUDE
0°
40°E
80°E
120°E
160°E
160°W
120°W
80°W
40°W
0°
LONGITUDE
1500
150
100
60
30
10
8
6
4
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.08
0.06
0.04
0.02
0
CS (Bq/m3)


FERRET Ver. 5.81
NOAA/PMEL TMAP
Sep 13 2013 09:52:33
TIME : 21-APR-2011 10:29
DATA SET: res4_0000
45°N
35°N
25°N
15°N
5°N
LATITUDE
110°E
120°E
130°E
140°E
LONGITUDE
1500
150
100
60
30
10
8
6
4
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.08
0.06
0.04
0.02
0

Outline

1 Introduction

2 Model description and Method

3 Surface spreading of the Fukushima-derived cesium

4 Southward(Vertical) spreading of the Fukushima-derived cesium

5 Conclusions

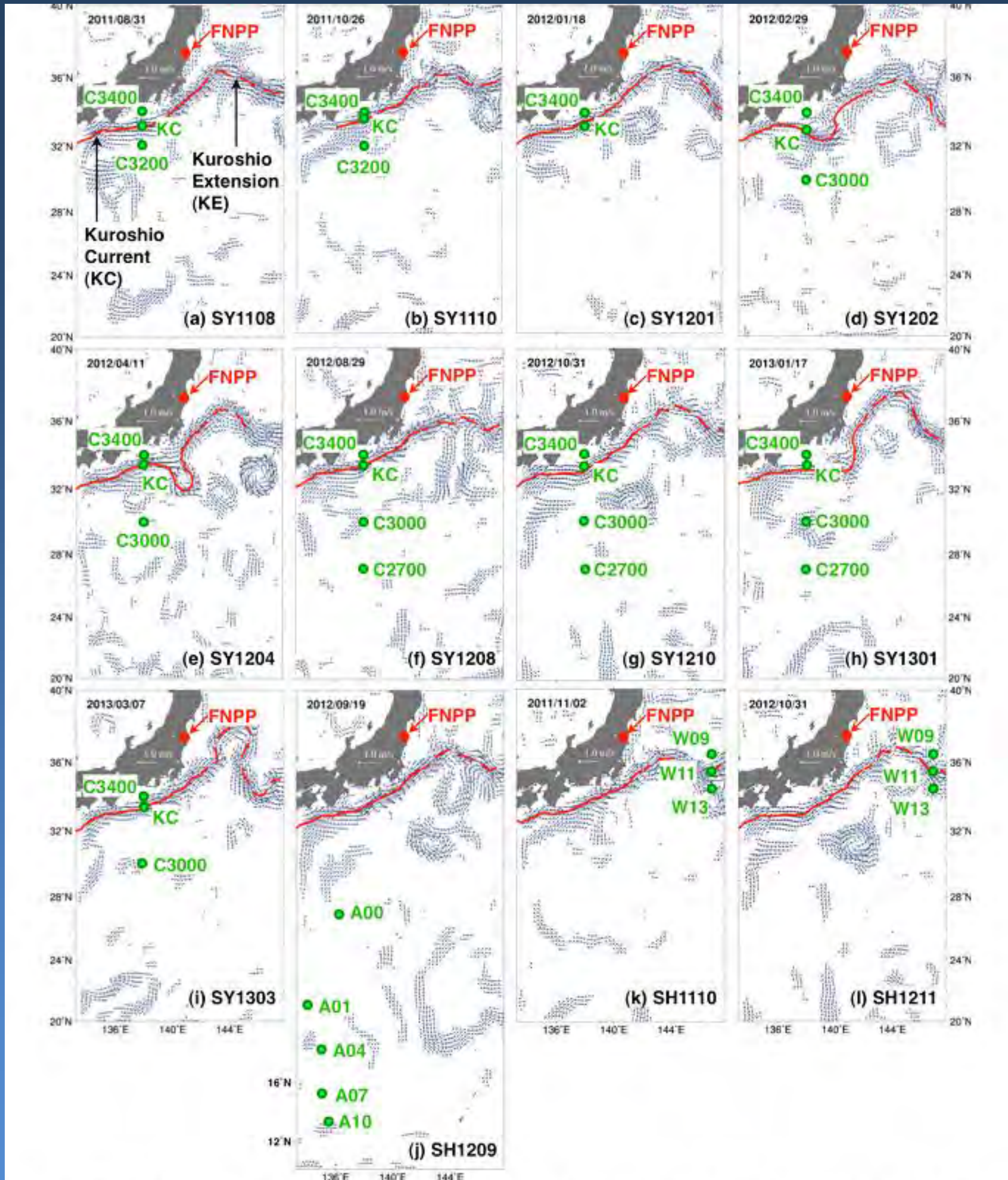
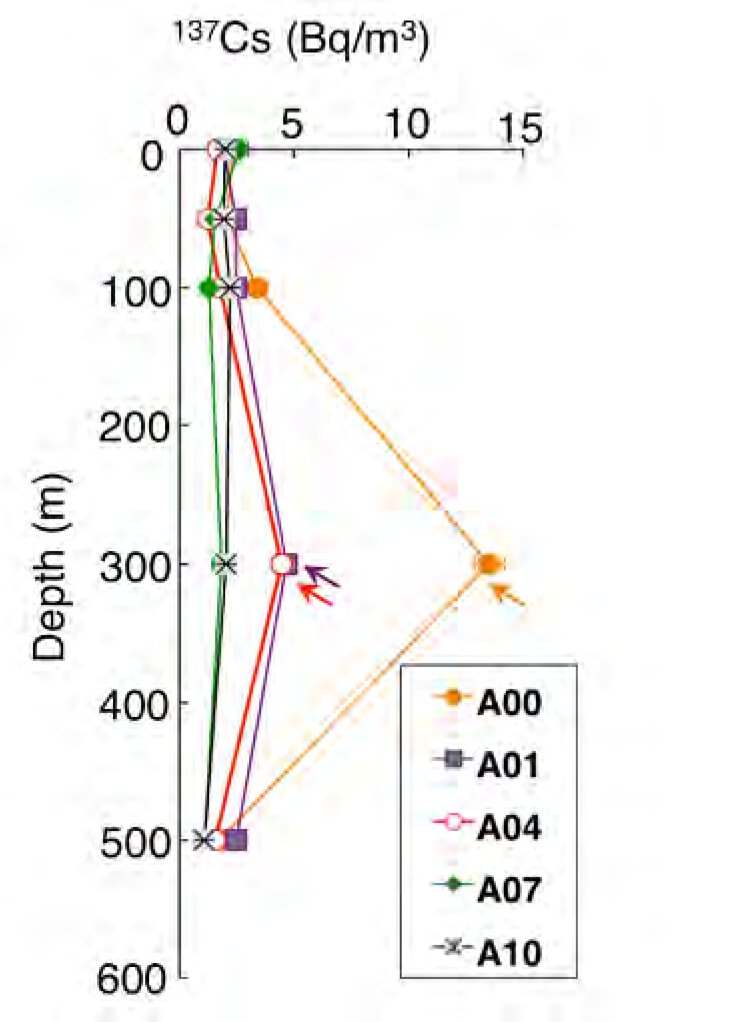
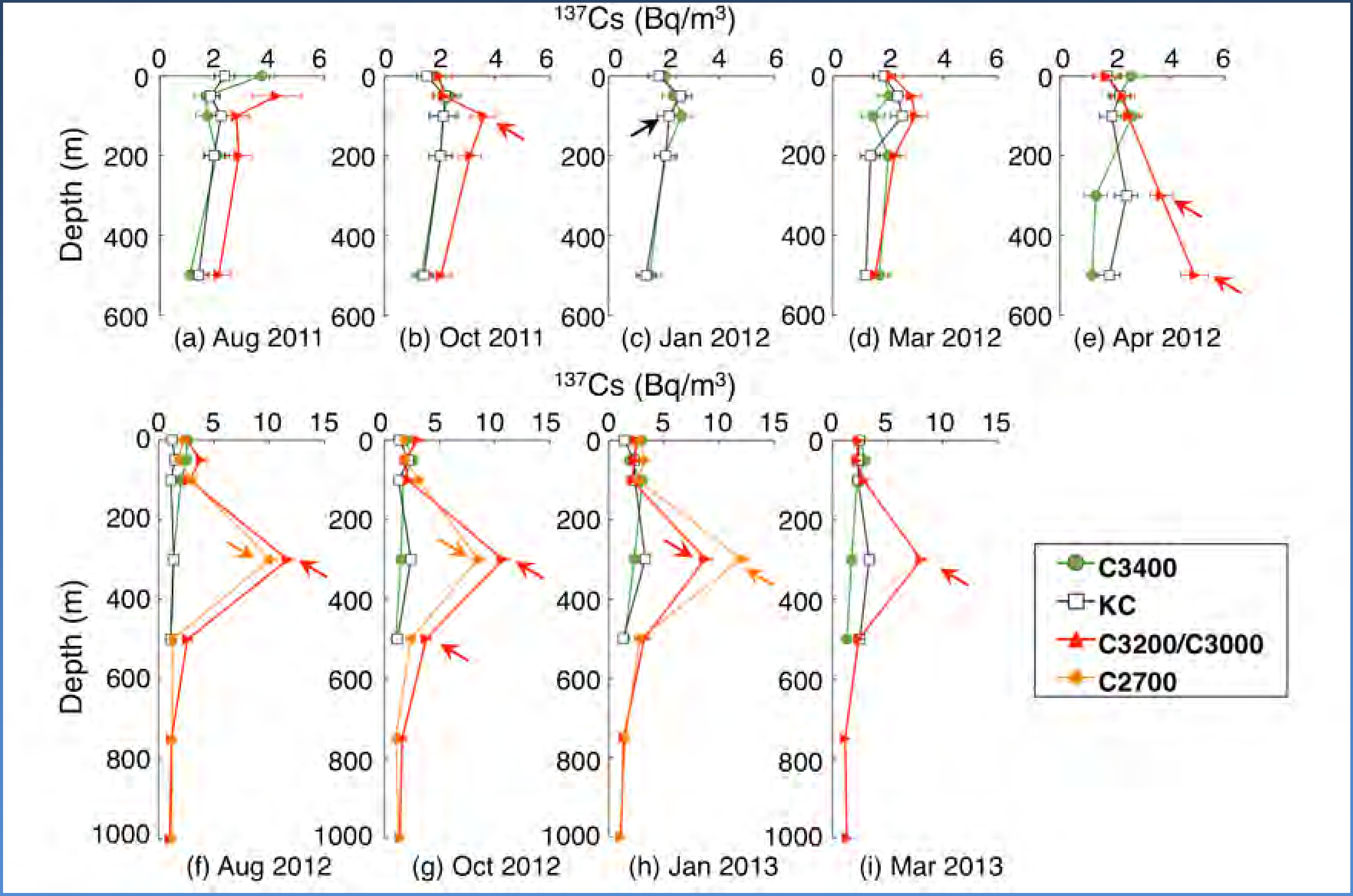


Figure 1. Sampling locations for radioactive cesium in the western North Pacific. Red circle indicates the Fukushima Dai-ichi Nuclear Power Plant, and green circles indicate the sampling stations. Brue arrows indicate surface velocity fields (>1.0 m/s) estimated from a satellite altimeter. The date of the fields is a closer one to the cesium observation. The red bold line and red broken line indicate the Kuroshio Current (KC) and Kuroshio Extension (KE), respectively. The positions of KC and KE were estimated by satellite altimeter data and sea surface drifter data.[5]

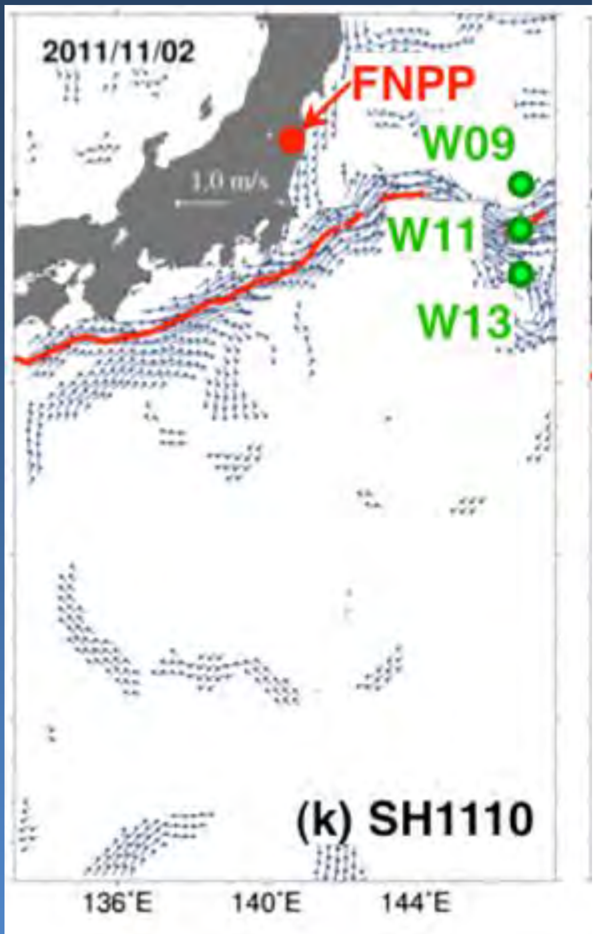


September 2012

Kaeriyama et al. 2014



Kaeriyama et al. 2014



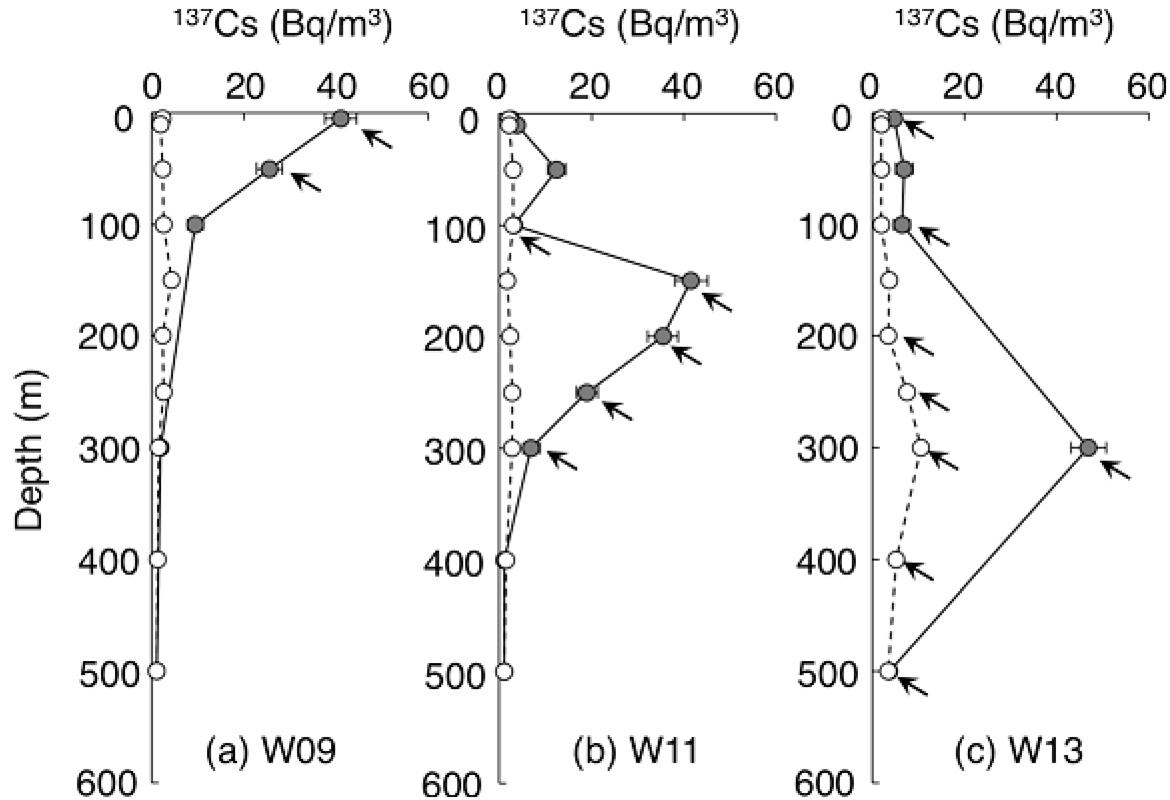
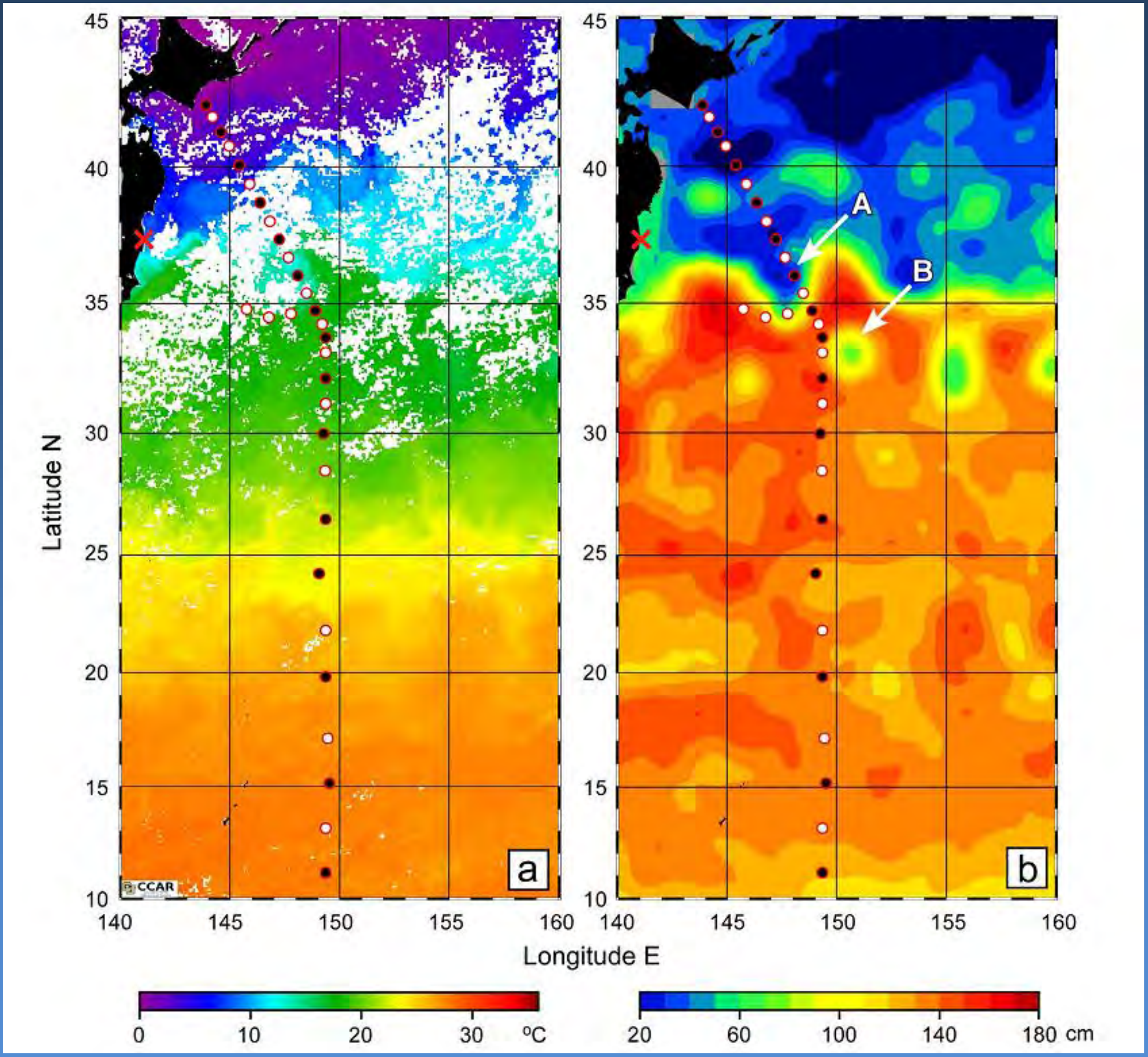


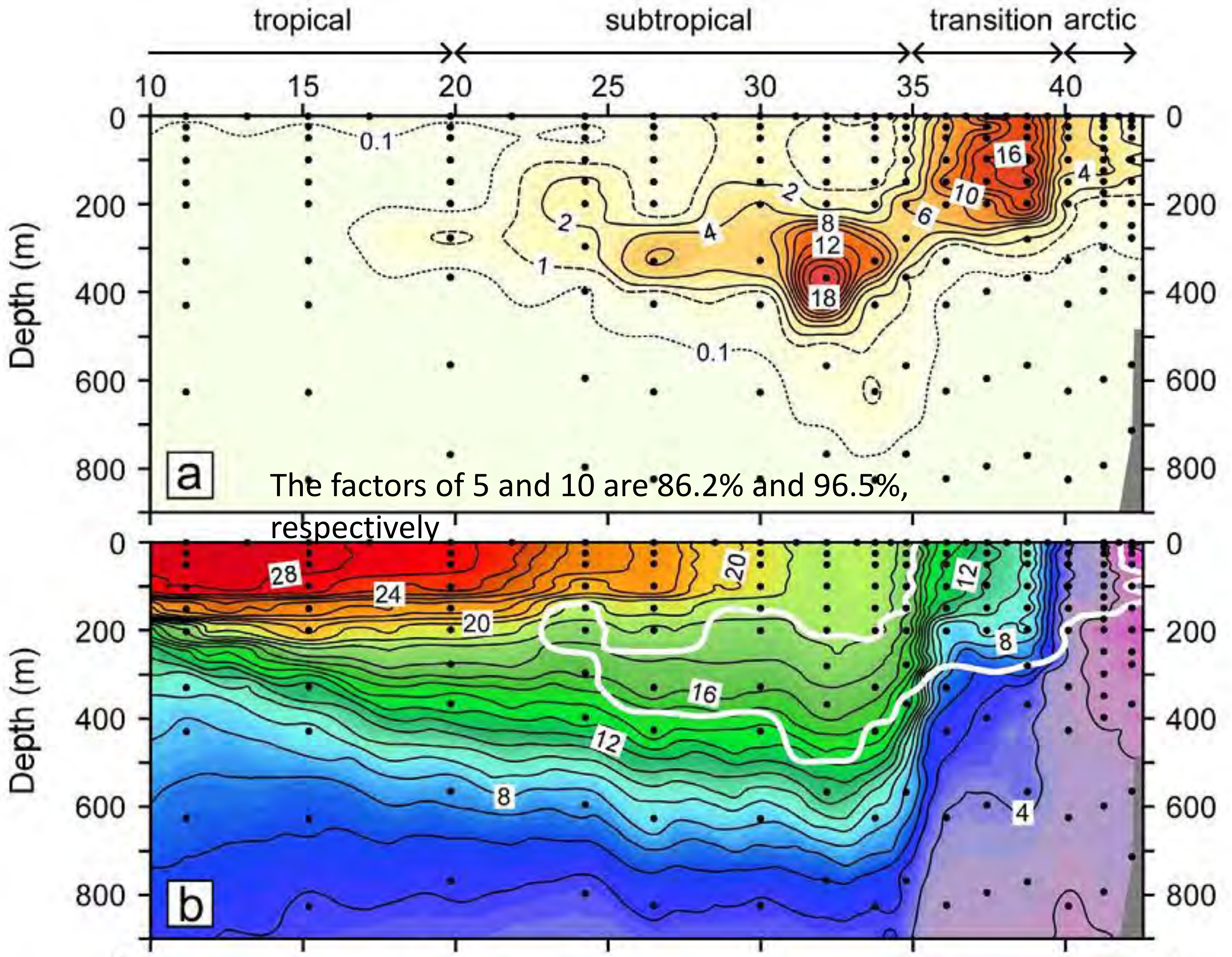
Figure 4. Vertical profiles of ^{137}Cs at (a) W09 (north of the KE), (b) W11 (KE), and (c) W13 (south of the KE). Gray circles with a solid line represent values recorded in October 2011. White circles with a broken line represent values recorded in November 2012. Arrows indicate the detection of ^{134}Cs. Error bars indicate counting error ($\pm 1\sigma$). When ^{137}Cs was under the detection limit ($<3\sigma$), the detection limit was plotted (see also SI Table S1).

Dash line October 2011
Solid line November 2012

Kaeriyama et al. 2014



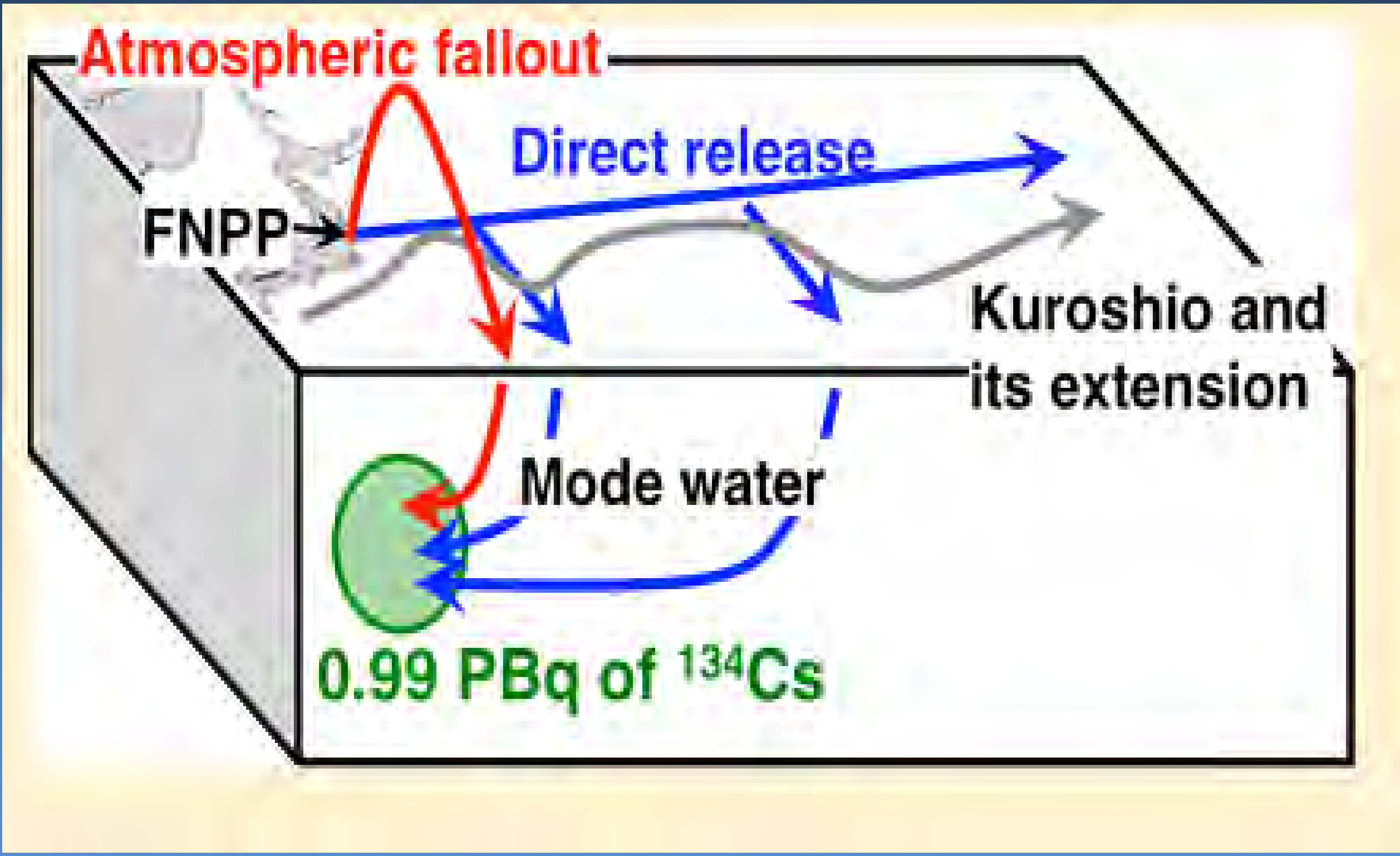
Kumamoto et al. 2014



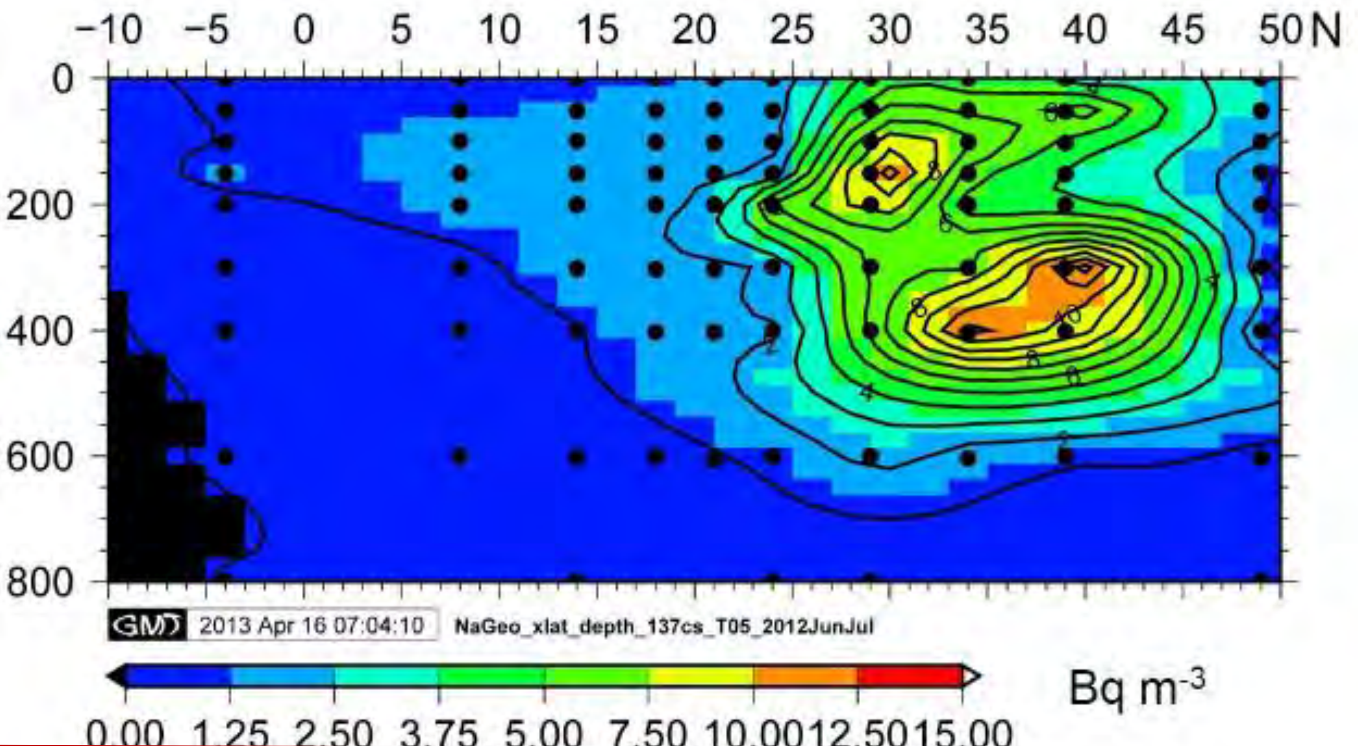
The factors of 5 and 10 are 86.2% and 96.5%, respectively

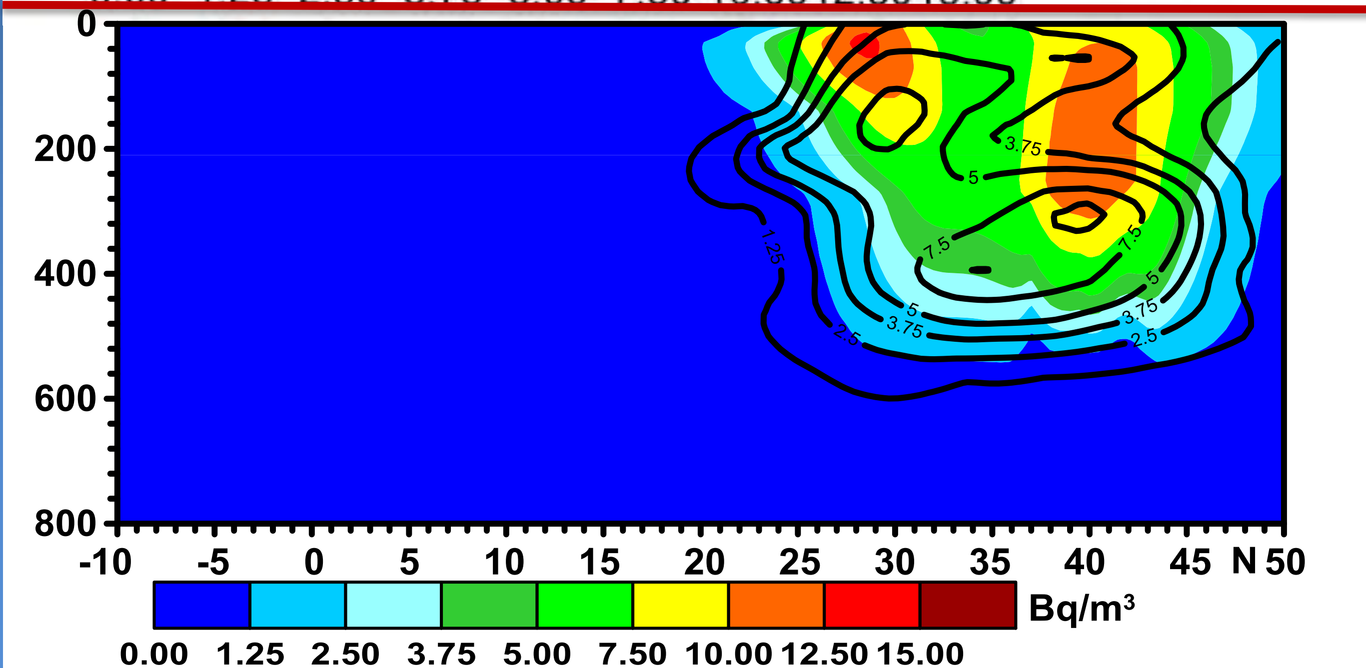
Up ^{134}Cs; Down Temperature;

Kumamoto et al. 2014



Atmospheric fallout
Direct release
FNPP
Kuroshio and its extension
Mode water
0.99 PBq of ^{134}Cs





Aoyama 2013

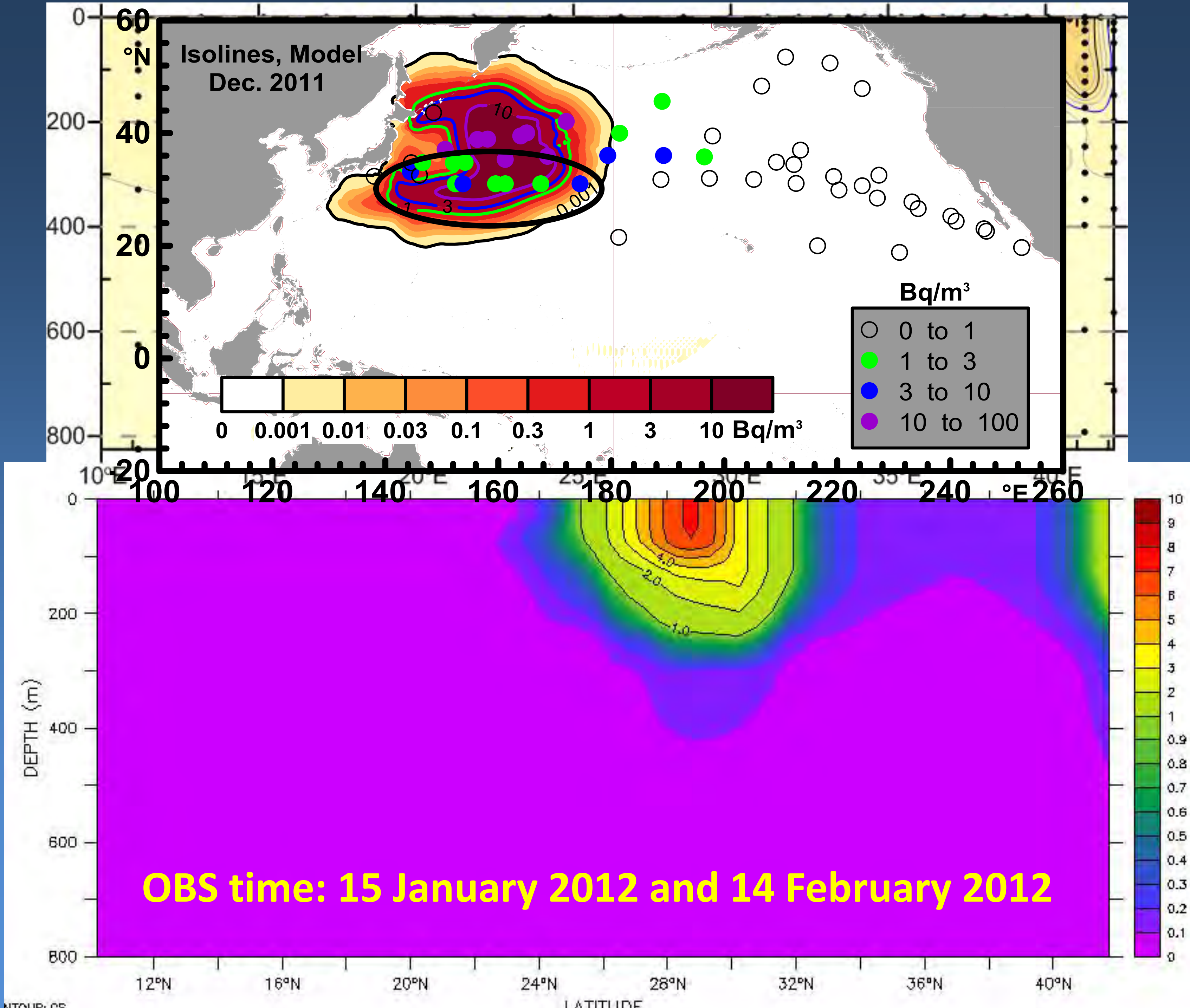
PowerPoint for IEAE

No published

165E section observation

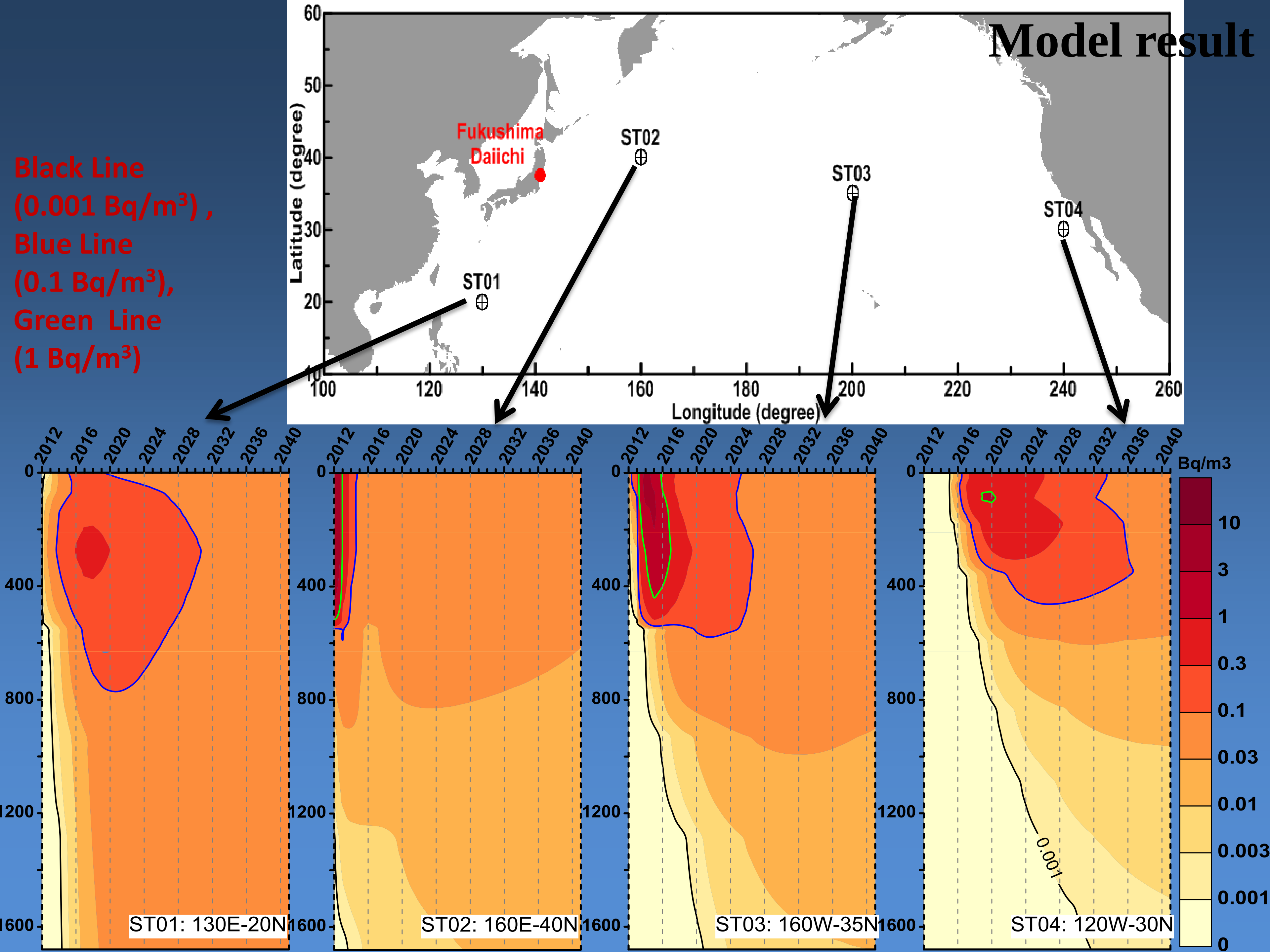
Time： 2012 06-07

Model： 2012 06

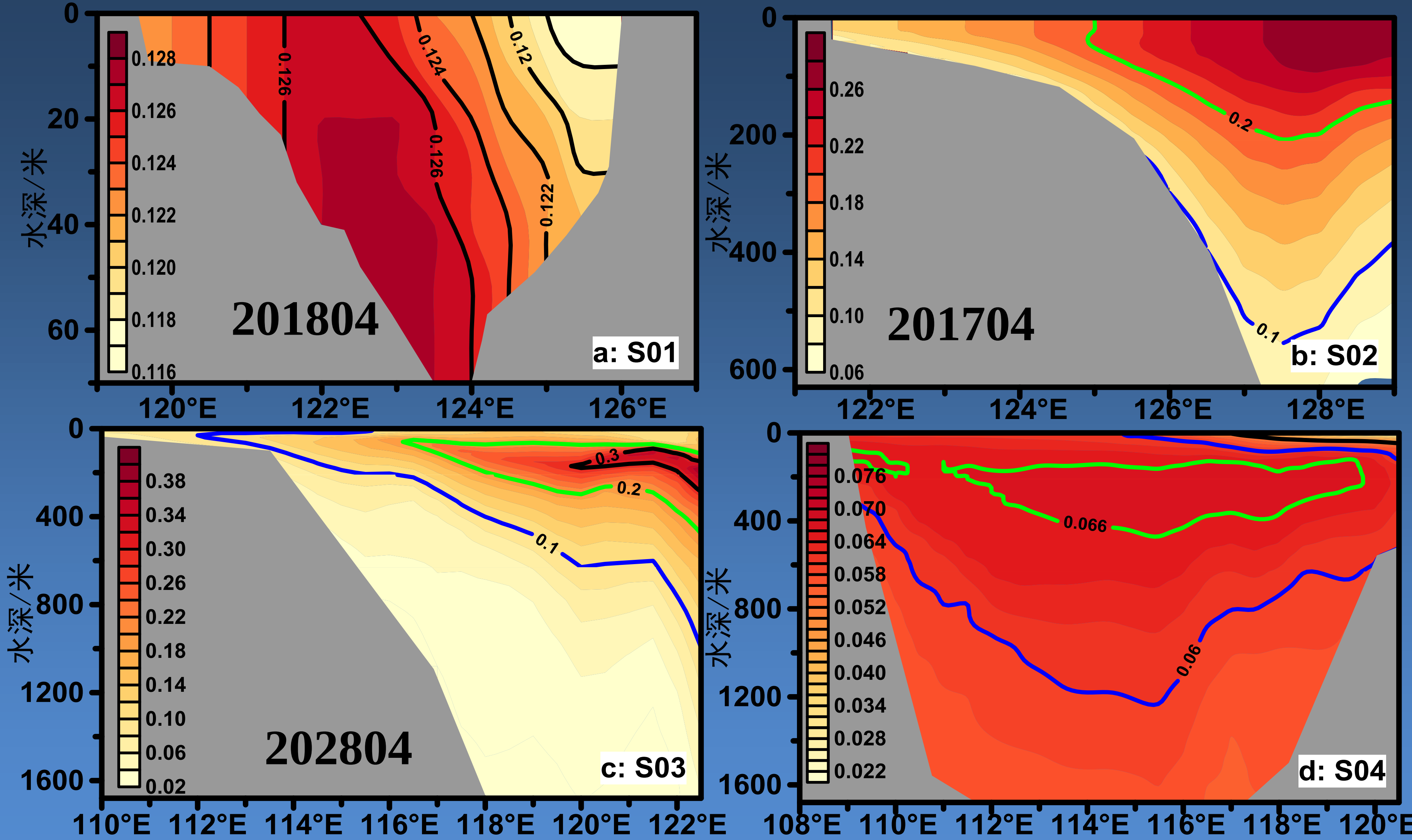


Isolines, Model
Dec. 2011
°N
60
40
20
0
20
100
120
140
160
180
200
220
240
°E 260
0
0.001
0.01
0.03
0.1
0.3
1
3
10 Bq/m³
Bq/m³
0 to 1
1 to 3
3 to 10
10 to 100
DEPTH (m)
0
200
400
600
800
12°N
16°N
20°N
24°N
28°N
32°N
36°N
40°N
LATITUDE
OBS time: 15 January 2012 and 14 February 2012

Black Line (0.001 Bq/m^3) , Blue Line (0.1 Bq/m^3), Green Line (1 Bq/m^3)



Model result



This figure is the distribution of ^{137}Cs in section Yellow Sea, East China Sea and South China Sea.

Outline

1 Introduction

2 Model description and Method

3 Surface spreading of the Fukushima-derived cesium

4 Southward(Vertical) spreading of the Fukushima-derived

5 Conclusions

Conclusions

- Fukushima-derived radionuclides spreading by both surface and subsurface ocean.

- We should set up some new models to study Fukushima-derived radionuclides spreading in the ocean.
  ------Fine resolution (Horizontal and Vertical)
  ------New sources radionuclides form Fukushima
  (Atmospheric, Rivers and Underground water)

Thank you !

zhaoc@fio.org.cn