Reply to Reviewer-#2

We appreciate the constructive review the manuscript. Below are shown your comments (in italics) and our response comments (in bold).

<Comment-1>

Why the simulations stops the 6 May 2011? Significative extended measurements are available up to July 2011 with results from MEXT; TEPCO; Aoyama et al., 2012; Buesseler et al., 2012; Caffrey et al., 2012; Honda et al., 2012; Inoue et al., 2012.

The main objective of this paper is the estimation of total caesium-137 (^{137}Cs) amounts of the atmospheric deposition and direct release into the ocean; the former (latter) event dominantly occurred within March (April) 2011, as indicated by Fig.2 (Fig.4). The target period from 12 March to 6 May 2011 in this paper reasonably covers these events. Total amount of a CRIEPI type direct release function (JCOPE-T-2-C; see Table 3) increases only 0.1PBq even if it covers an extended period until 30 June 2011, as compared to the total amount of 5.9PBq for our target period. Also note that our estimation is comparable with the other previous estimates based on the data during the similar period (Kawamura et al., 2011; Tsumune et al., 2012).

We generally agree the reviewer's suggestion on the measurements for the extended period. We will add a following description in the end of the paragraph beginning at line 13, p.13797:

'To reduce the uncertainty, additional studies based on the observation data obtained during the extended period (e.g., Aoyama et al., 2012; Buesseler et al., 2012; Caffrey et al., 2012; Inoue et al., 2012) could be required as well as additional model simulations (e.g., Dietze and Kriest, 2012).'

Reference:

Dietze, H., and Kriest, I.: ^{137}Cs off Fukushima Dai-ichi, Japan – model based estimates of dilution and fate, Ocean Sci., 8, 319-332, 2012.

<Comment-2>

Statistical quantification of the average differences between measured and simulated concentrations must be presented (normalized gross error and normalized bias error for example).

We will add figures showing mean errors (biases) and root mean square error of a first guess simulation (JCOPE-T-2-C; see Table 2) and its correspondence with adjusted source parameters (JCOPE-T-2-C-E; see Table 3). They will be added after Fig.10.

A description relevant to Fig.R1 (new Fig.11 in the revised paper) will be included in Section 5. See below.

'Normalized error distribution between a first guess simulation (JCOPE-T-2-C; see Table 2) and the observations generally indicates underestimation of the surface concentration (Fig.11, BIAS-1). The adjustment of the parameters slightly improves the underestimation (Fig.11, BIAS-2). Overestimation of the surface concentration near FNPP in a case assuming a larger amount of 14.8 PBq of the direct release (see Table 1 of Masumoto et al., 2012 and Fig.8a of Miyazawa et al., 2012) partly supports the present estimates of 5.6-5.9PBq, and underestimation in the region far from FNPP for the case with the larger amount of the direct release (again compare Fig.11, BIAS-2 and Fig.8a of Miyazawa et al., 2012) suggests the roles of the atmospheric deposition in the wide-range dispersion. Distribution of root mean square error in the adjusted parameters case (Fig.11, RMES-2) shows better skill than those of smaller (3,5PBq; Fig.11, RMSE-1) and larger (14.8PBq; Fig.8b of Miyazawa et al., 2012) amounts of the direct release. '

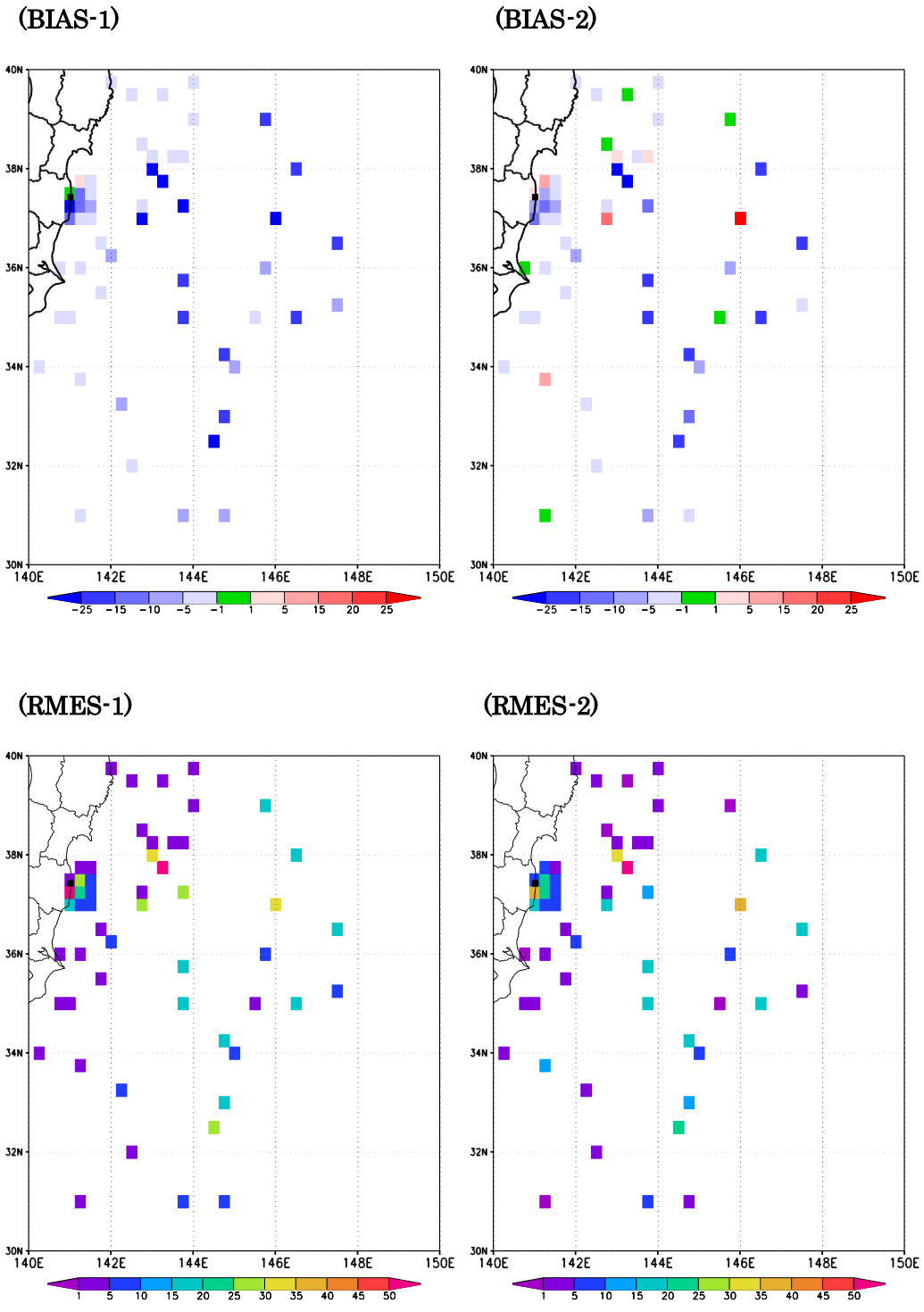


Fig.R1. (new Fig.11) Gridded distributions of mean error (BIAS) and root mean square error (RMSE) between the simulated and observed ^{137}Cs surface concentration for the period from 21 March to 6 May 2011, normalized by the measurement errors (See Table 1). Grid resolution is 1/4°. The position of FNPP is denoted by a closed square. Left (right) panels denote the JCOPE-T-2-C (JCOPE-T-2-C-E) case.

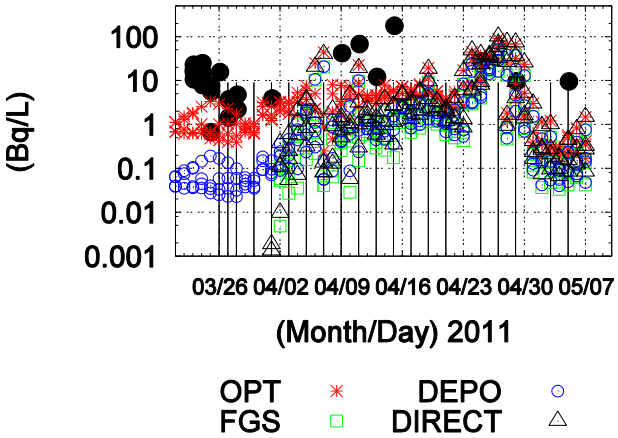
<Comment-3>

In situ measurements are sufficient enough to made possible comparison between measured and simulated environmental half time and inventory of 137Cs quantities. The general reliability of the simulations could be tested in this manner with demonstration of how the models simulate the general dispersion process.

This comment suggests an interesting view point. To elucidate general features of our simulations as compared to the observations, we examine temporal variations of the measurements on the MEXT monitoring points approximately 30km off the coast together with the simulated concentrations, as shown in Fig.R2 (new Fig.12 in the revised paper). We recognize a difference between the simulation skills at the northeast and those at the southeast points. Note that the half-life effect is negligible as compared to the advection and diffusion since the half-life time scale of ^{137}Cs is 30.1 year. We will add a description relevant to new Fig.12 as follows:

'The observations obtained at the MEXT monitoring points northeast of FNPP (see open triangles in Fig.12c for locations) indicate three peaks of the surface concentration in the end of March, middle of April, and end of April 2011 (Fig.12a). The JCOPE-T-2-C-E case generally represents these three peaks. The first peak in the end of March is caused by the atmospheric deposition, because the only simulations with the deposition represent the increase of the concentration in this period (see asterisks and open circles in Fig.12a). The direct release is responsible for the two peaks in April (see open triangles in Fig.12a). The observation southeast of FNPP also shows the similar three peaks (Fig.12b). The simulations basically underestimate the concentration in this region. Figure 12c indicates that the ocean current facilitates the northeastward elongation of the dispersion and prevents the southward transport of ^{137}Cs in April and May 2011. This feature is generally consistent with the observation around the southern part of the Japan coast (Aoyama et al., 2012). The simulated current slightly different from the real state could considerably affect the dispersion around the monitoring points.'

(a)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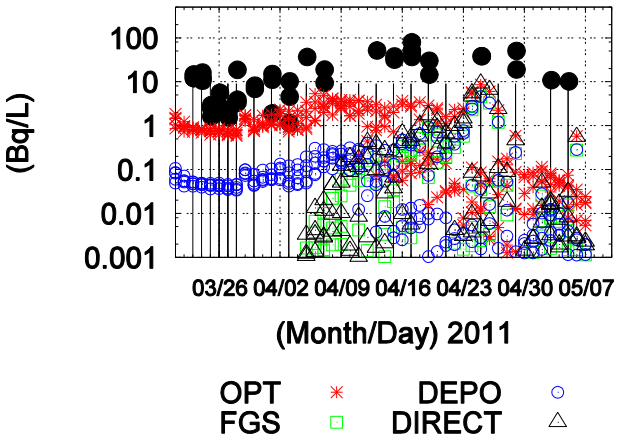
(b)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(c)

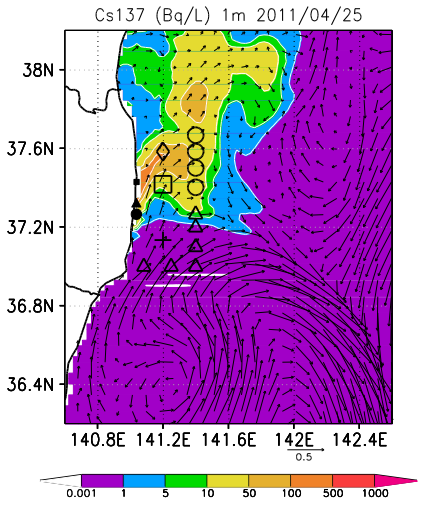
Cs137 (Bq/L) 1m 2011/04/25
38N
37.6N
37.2N
36.8N
36.4N
140.8E 141.2E 141.6E 142E 142.4E
0.5
0.001 1 5 10 50 100 500 1000

Fig.R2. (new Fig.12) (a) Time sequences of ^{137}Cs at 1m depth on the points northeast of FNPP, denoted by open circles shown in (c). Closed circles: MEXT observation (See Table 1). Asterisks: JCOPE-T-2-C-E. Open squares: JCOPE-T-2-C. Open circles: the sensitivity experiment for the atmospheric deposition. Open triangles: the sensitivity experiment for the direct release. Vertical bars: measurements reporting ^{137}Cs activities below the detection limit, 10 Bql^{-1}. (b) As in (a) except for the points southeast of FNPP, indicated by open triangles shown in (c). (c) Daily mean ^{137}Cs concentration (in Bql^{-1}) on 25 April 2011 at 1m depth (shaded) simulated by the JCOPE-T-2-C-E case. Vectors indicate the daily mean current at 1m depth. The position of FNPP is denoted by a closed square. The TEPCO monitoring points are indicated by a closed triangle (Fukushima Daini nuclear power plant), a closed circle (the Iwasawa Coast), an open diamond (15km off Minamisoma), an open square (15km off FNPP), and a plus sign (15km off Hirono). The MEXT monitoring points are indicated by open circles and triangles.

<Comment-4>

Figures 5 and 8 must be enlarged and quality improved. Significant differences between measured and simulated concentrations appear in Fig 8, the color scale applied made difficult to appraise these differences.

Enlarged images of Figs. 5 and 8 are included in this document for help of checking them. Also check Fig.R2 for comparison between the observation and simulations.

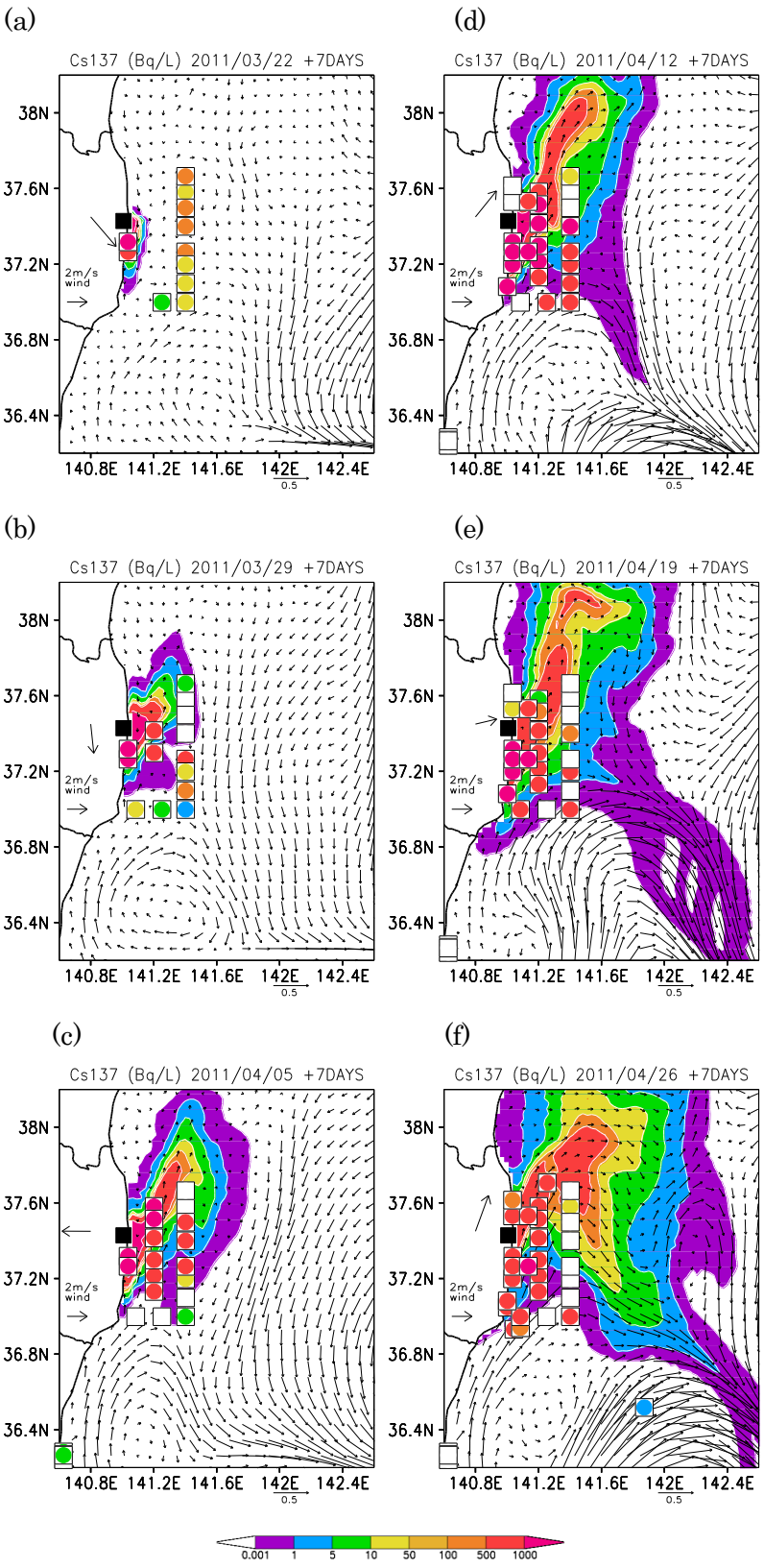

Fig.5 (enlarged)

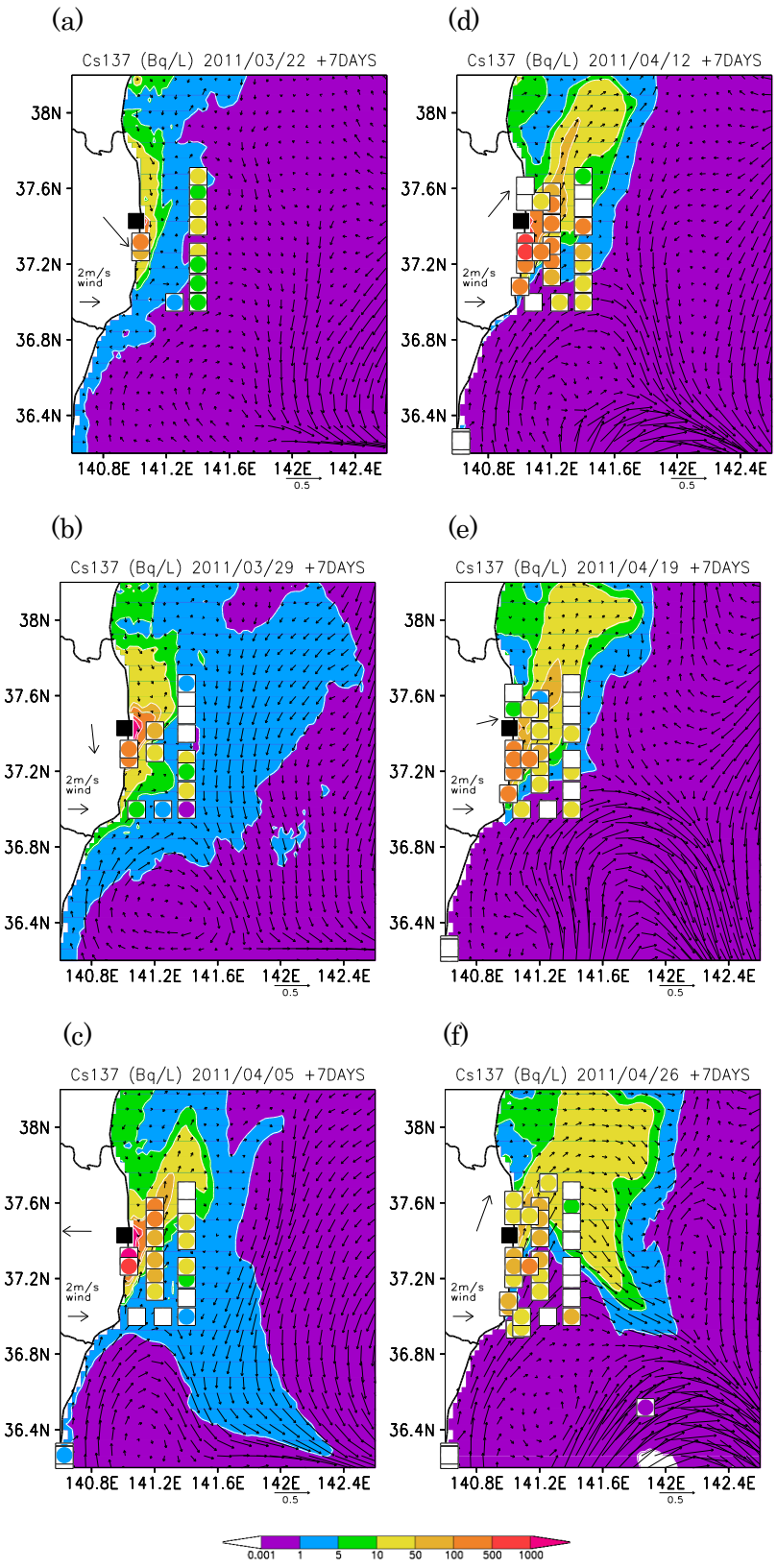

Fig.8 (enlarged)

<Comment-5>

Fig. 10 must present results at stations at 15 and 30 km from the coast, which are more representative of the dilution in the Oyashio/Kuroshio mixing area.

We will add new 3 images (Figs.10d, e, and f) showing the results at 15km off the coast. New Fig.12 shows the results at 30km off the coast. See below.

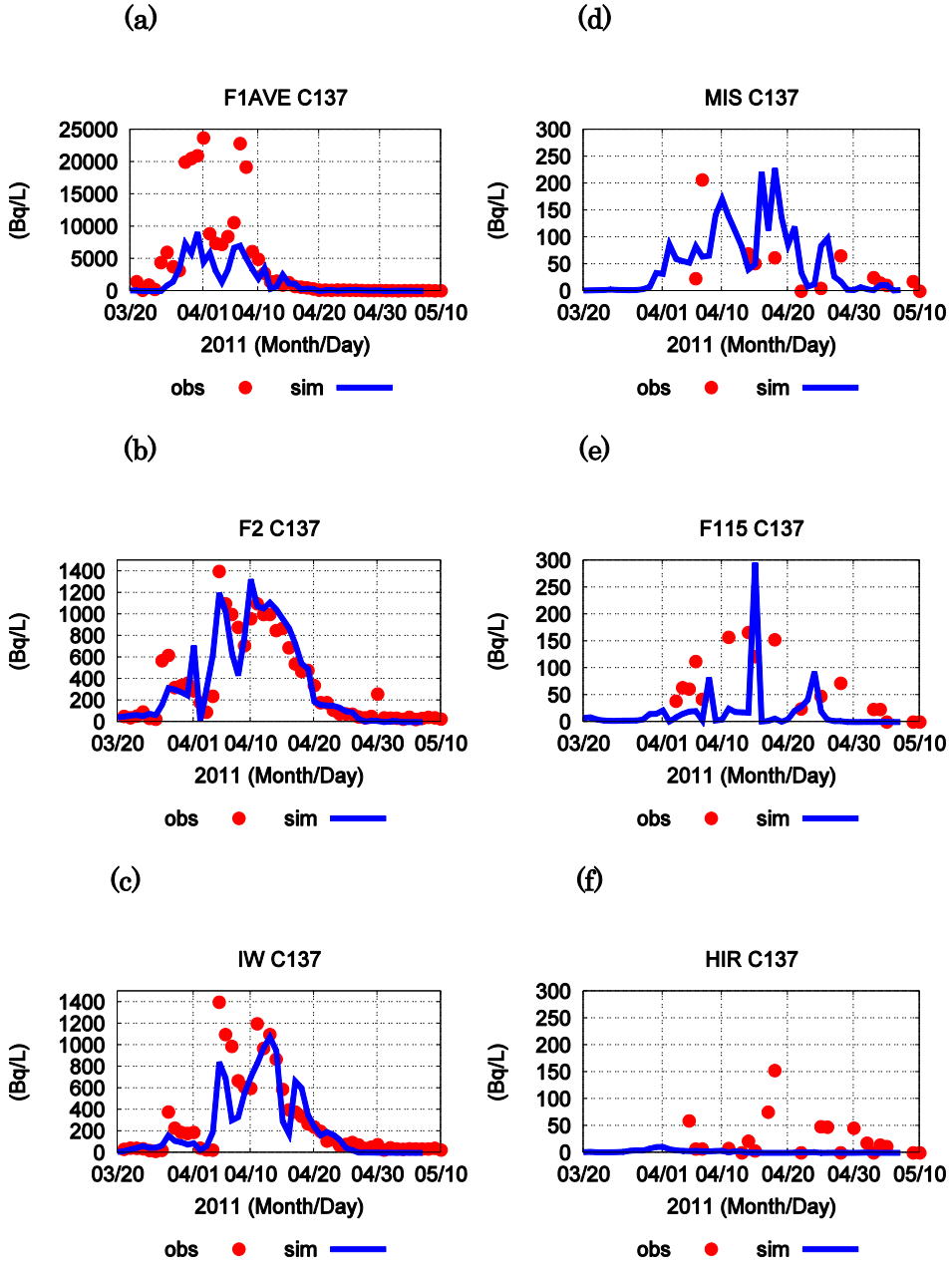

Fig.10 (enhanced)

An updated description relevant to enhanced Fig.10 in the revised paper is as follows:

'The optimized parameters allow to represent time sequences of ^{137}Cs variations near FNPP: in front of FNPP, in front of Fukushima Daini nuclear power plant (10 km south of FNPP), and the Iwasawa Coast (16 km south of FNPP), as observed (Figs. 10a, b, and c; See Fig.12c for locations), though the peak magnitude of the observation in front of FNPP (Fig. 10a) is not completely reproduced due to the coarse grid (1/36°) of the model. The simulation assuming a flat shape of the CRIEPI type flux sequence during the period from 26 March to 6 April 2011 (Fig. 4) reproduces two peaks of the observation in April 2011 as shown in Fig. 10a and results in the smallest cost function value among the all simulations after the parameters optimization (Table 3), suggesting that the ^{137}Cs variation in front of FNPP is basically caused by not the direct release flux but the ocean current variation as mentioned by Tsumune et al. (2012). Comparison between the measurements and simulation at the TEPCO monitoring points 15km off the coast (Figs.10d, e, and f) indicates that the simulation comparatively reproduce the dispersion northeast of FNPP (Figs.10d and e) while it underestimates the concentration southeast of FNPP (Fig.10f). The difference of the skill between northeast and southeast of FNPP does not much affect the estimation of the source parameters, because the observations along the coast near FNPP (Figs.10b and c) dominantly contribute to the estimation (Fig.6 O-1 and A-1). '

<Comment-6>

If Table 3 presents the result of the best estimates, give the range of values tested. If it is not the case, a wider range of ocean and atmospheric multiple would be presented to appraise why the 5.9 and 9.5 values are finally selected.

Table 3 presents the results of the source parameters optimization using the Green's function approach for the different types of simulations with different horizontal resolutions, ocean current products, and direct release fluxes. The 5.9 and 9.5 values of the total emission amounts are taken from the optimization (JCOPE-T-2-C) resulting in the smallest cost function value among those from the optimization cases listed in Table 3.

<Comment-7>

Discuss the independence in time and space of the oceanic and atmospheric source terms as one contribution could masks the other and inversely. In particular, atmospheric contribution is characterized by a larger extent of deposit than the direct release. Could it mask a combined underestimation of the model dilution and oceanic

contribution?

This interesting comment suggests an important viewpoint for deeper understating the oceanic dispersion of ^{137}Cs originating from FNPP. We will add the following description in section 5.

'The dominant contributions from atmospheric and oceanic sources could be found in the different periods. The atmospheric deposition started from 12 March 2011 and the peaks of the emission were found only within March 2011 (Fig.2). The dispersion within March was mainly forced by the atmospheric source. Comparison of the surface concentration on the MEXT monitoring points between the simulations with and without the atmospheric source (compare open circles and squares in Figs.12a and b) suggests that the concentration in March was caused by the atmospheric deposition around the monitoring points. In contrast, the direct release begun from 26 March (Tsumune et al., 2012) and its dominant effect there appeared from April (Again see Figs.12a and b). The horizontal scales of the two processes were also different from each other at least during our target period from 12 March to 6 May 2011. The dispersion triggered by the direct release was basically limited within the shelf region throughout the period (Fig.7a) but the atmospheric deposition affected the wide region over the Western North Pacific (see Fig.3 in Honda et al., 2012). We thus suggest that comparable contributions from both the atmospheric and oceanic sources did not occur except for in a narrow region along the coast very near FNPP in the end of March 2011. '

Note that the worse skill of the coarse grid model (JCOPE2) causes the failure of the parameters estimations resulting in the negative value of the total amount of the atmospheric deposition (Table 3), which comes from the unrealistic compensation between the exaggerated direct release effect and the atmospheric deposition (Fig.7). The discussion about the contribution rates (see Section 5 and Fig.6) is provided for emphasizing this aspect.

<Comment-8>

A map showing the total spatial distribution of the atmospheric deposit is not presented. Is it the same as from Fig.3 in Honda et al? In this case give the reference. If it is not, include a figure with the deposition map used.

Yes, we provided the relevant description in the end of subsection 2.1 as follows:

'Horizontal distribution of the accumulated deposition is depicted in Honda et al. (2011)'s Fig. 3.'

<Comment-9>

Honda et al. do not present the time evolution of the atmospheric deposit. In Mathieu et al it appears that the end of the main atmospheric release is 17 March, do you agree? In this case, the 28-29 March deposition in Fig 2 appear late (10 days after). A consequence is that the oceanic and atmospheric contributions are more difficult to distinguish as they are nearly simultaneous.

The simulation of the atmospheric deposition (Honda et al., 2011) indicates the peak around 28-29 March 2011 (Fig.2) as mentioned by the reviewer. This is because the simulation is based on the source term of the atmospheric release proposed by Chino et al. (2011). See Fig.4 in Chino et al. (2011).

<Comment-10>

Fig. 6 gives average contribution rates of the ocean and atmospheric parameters. I suppose this average encompass the whole simulation period (11 March – 6 May). It would be interesting to distinguish two periods: after the end of the atmospheric deposit (1 – 10 April for example), and at the end of the simulation (beginning of May).

This suggestion is interesting. We conducted the parameters optimization of the JCOPE-T-2-C case for different two periods: 21 March – 31 March and 1 April – 6 May 2011. See Table R1 and Fig.R3.

Table R1. Summary of the parameters optimization results of the JCOPE-T-2-C case for the different periods. Two-digit numbers denote estimated total amounts of ^{137}Cs emission in PBq.

	Ocean-Multiple	Atmosphere-Multiple
JCOPE-T-2-C (21 March to 6 May 2011)	5.9	9.5
JCOPE-T-2-C (21 March to 31 March 2011)	10.9	8.7
JCOPE-T-2-C (1 April to 6 May 2011)	5.9	8.1

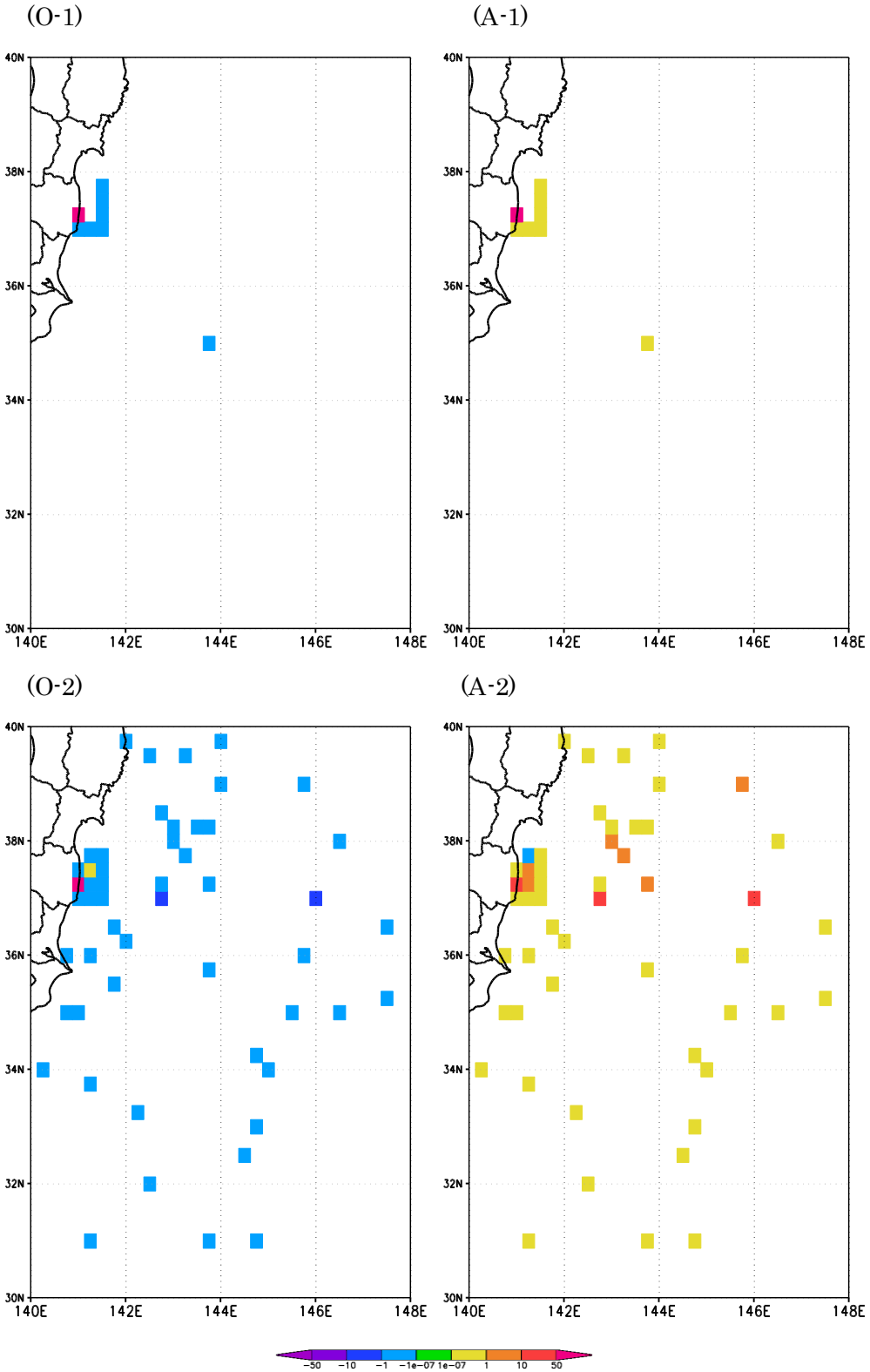

Fig.R3. Contribution rates (in %; Eq. 9) averaged in 1/4° x 1/4° grids. (O-1) The ocean parameter in the JCOPE-T-2-C case for the period from 21 to 31 March 2011. (A-1) As in (O-1) except for the atmospheric parameter. (O-2) As in (O-1) except for the period from

1 April to 6 May 2011. (A-2) As in (O-2) except for the atmospheric parameter.

Both the atmospheric and ocean parameters are basically determined from the observation along the coast near FNPP (Fig.R3, O-1 and A-1) in the case for March 2011. The total amount of the direct release is estimated as a larger value as compared to the cases for the other periods, but it is estimated as smaller values if the measurements after April are included in the cost function. Negative values of the contribution to the ocean parameter estimation except for the measurements along the coast in this case suggest the very limited horizontal scale of the dispersion due to the direct release within March. The patterns of the contribution rates in the case for April (Fig.R-3, O-2 and A-2) and estimates total amounts (Table R3) are generally similar to the case for the whole period (Fig.6, O-1 and A-1).

<Comment-11>
What explain the colored dots distribution, are they the locations of in situ measurement?

The colored dots denote the contribution rates for the measurements averaged in 1/4° x 1/4° grids. See the caption of Fig.6.

<Comment-12>
P.13798 line 15: Is 38.5°-43.3° N, 138.5°-145.6° E the good area? Fukushima area is not included.

This is a wrong description. The exact description is '30.5°-48° N, 127°-154.5° E'. Thank you for the notice.

<Comment-13>
P. 13786, line 20: The period duration is missing? (30 years).

We will correct as 'A constant value $\lambda = \ln(2)/T_{half}$ $\left(T_{half} = 30.1\text{years}\right)$ represents the half-life time decay effect of the radionuclide for ^{137}Cs.'

<Comment-14>

P. 13787, line 9: "." is missing before "Note".

Yes, we will add '.'.

<Comment-15>

P. 13791, line 18: "." is missing after Bq in Bq.l-1 (two times).

Yes, we will add '.'. Thanks.