[Referee #2 comment]

(P.12729, L.25 - P.12730, L.6) You cannot really say that your results are "largely consistent with the earlier simulations". The simulation result from the end of March to the beginning of April of Fig. 4(a) seems 0.1 times of the observation. This tendency of underestimation is stronger than 0.5 times of Fig. 10(a) of Miyazawa et al. (2013). Quite large amount of Cs-137 measured around 1FNPP during the period from March 26 to April 9. The initial bottom sediment contamination was strongly affected by the surface Cs-137 concentration of this period. Examining the results from March 26 to April 9 of Fig. 4(a), in spite of using direct discharge from 1FNPP like Miyazawa et al. (2013) and extremely huge amount of atmospheric deposition, I believe this outcome is not supported clearly enough.

[Response]

One of the reasons for the discrepancy between surface-seawater ^{137}Cs simulated by our model and that of Miyazawa et al. (2013) is ^{137}Cs behaviours of adsorption on suspended particulate matter and subsequent downward sinking. Those behaviours are considered in our model but not in Miyazawa's. These processes including resuspension and horizontal transport are important for ^{137}Cs migration from seawater to seabed and redistribution of sedimentary ^{137}Cs (Otosaka and Kobayashi, 2013). The processes have commonly been considered in models of ^{137}Cs sedimentation (e.g., Kobayashi et al., 2007; Periáñez et al., 2012; Choi et al., 2012), as with our study. As a result of ^{137}Cs sinking, seawater-surface ^{137}Cs simulated by our model would be smaller than that in Miyazawa's model, if identical ^{137}Cs inflow conditions are given. By contrast, our simulation requires greater atmospheric ^{137}Cs deposition than Miyazawa's to produce the same surface-seawater ^{137}Cs activity. This also indicates that ^{137}Cs inflow of direct discharge and atmospheric deposition estimated by Miyazawa et al. would be underestimated if the ^{137}Cs sinking were non-negligible.

Another reason for the discrepancy between surface-seawater ^{137}Cs from our model and that of Miyazawa et al. is that our spatiotemporal variation of atmospheric ^{137}Cs deposition is probably different from the latter work. Hence, our atmospheric ^{137}Cs deposition at any location or time does not necessarily exceed that used by Miyazawa, even though the total amount of atmospheric ^{137}Cs deposition over the ocean in the former simulation is greater than in the latter.

Given the above differences in numerical procedures and/or the simulation conditions, there was no earlier simulation that quantitatively agreed with our spatiotemporal distribution of seawater ^{137}Cs. Hence, the referee comment of "You cannot really say that your results are largely consistent with the earlier simulations" is absolutely correct. We confirmed that our seawater ^{137}Cs dispersion (Figs. 4 and S2) was qualitatively consistent with the earlier simulations. For instance, the discrepancy between our simulation and the observation had similar characteristics in the earlier studies, as follows. Our simulation tended to underestimate sea-surface ^{137}Cs southeast of 1FNPP (as at stations W-8 through W-10; Fig. 4g–i) per the earlier simulations (Kawamura et al., 2011; Tsumune et al.,

2012; Miyazawa et al., 2013). We revised Sect. 3.1 (pg. 12729, L1 − pg. 12730 L6) as section Revision #2-1 to briefly provide the above description.

In addition, we believe that quantitative uncertainty of our results should also be described briefly and more clearly. Atmospheric ^{137}Cs deposition is one of the factors in the uncertainty. Spatiotemporal variation of that deposition over the ocean, which has been estimated by numerical simulation in several studies besides Miyazawa et al. (2013) and Morino et al. (2011), had relatively great uncertainty. These total depositions also had wide variation (e.g., 5 PBq within 30.5°–48.0°N, 127.0°–154.5°E through the end of April, Kawamura et al., 2011; 7.6 PBq in the North Pacific through the end of April, Kobayashi et al., 2013; 28 PBq in the oceans through 20 April, Stohl et al., 2012). The present simulation used source data that were 1.65 times the direct discharge from 1FNPP of Tsumune et al. (2012) and 6.00 times the atmospheric deposition of Morino et al. (2011). Although this simple scaling reduced the discrepancy between observed and simulated seawater surface ^{137}Cs, we could not validate the ^{137}Cs inflow conditions in detail because neither the direct discharge nor the atmospheric deposition can be measured directly. We attempted validation by comparing observed and simulated vertical sedimentary ^{137}Cs profiles, but could not do so adequately because of a lack of data (as in Sect. 3.3). We revised Sect. 2.2 as section Revision #2-2 to describe the aforementioned uncertainty in atmospheric ^{137}Cs deposition.

[Referee #2 comment]
P. 12725, L. 16 Perhaps instead of "in spited of", "in spite of" will fit better.

[Response]
We have revised per this comment.

[Referee #3 comment]
The authors employed complex model for Cs-137 concentration in seawater and sediment to represent the spatially heterogeneous distribution in sediment. I don't agree with their results of total amount of Cs-137 in sediment which is 10 times larger than previous estimated value based on observation. Main problem is that they only considered sedimentation and resuspension process in a similar manner to Europe. In Fukushima case, very high concentration of Cs-137 passed through on the sediment in the earlier period. Therefore, absorption and desorption process on sediment is dominant (Otosaka and Kobayashi, 2013). Sediment properties are a major factor of Cs-137 on absorption and desorption process. They did not considered these dominant processes. They simulated the sedimentation rates of Cs-137. The sedimentation rates were observed by sediment trap (Honda et al., Biogeosciences, 2013; Buesseler et al., ES & T, 2015). They should validate the sedimentation rates in comparison with observed data if they believe that sedimentation process is dominant. I think their simulated sedimentation rates are overestimated to observed value. If they simulate more than 2 or 3 years, difference between observation and their simulation is getting larger.

Because their model focus on sedimentation process which is not dominant in Fukushima case.

[Response]

Our model definitely includes the adsorption process of dissolved ^{137}Cs in bottom seawater to surface sediment, although this description was omitted in our original manuscript. In the model, exchange of dissolved ^{137}Cs between bottom seawater (Eq. (1)) and the surface seabed (Eq. (5)) was calculated from the diffusion equation. The diffusion coefficient was derived from bottom seawater turbulent and sedimentary bioturbation. In the model, adsorption of dissolved ^{137}Cs in bottom seawater to surface sediment can occur through diffusion. When high concentrations of the dissolved ^{137}Cs passed through just above the seabed, it infiltrated into sediment pore water through diffusion and was then adsorbed on sediment particles. We have added these explanations to Sects. 2.3 and 2.4 as section Revision #3-1.

We believe that the referee comment "absorption and desorption process on sediment is dominant (Otosaka and Kobayashi, 2013)" should be restricted to shallow regions. Indeed, the second conclusion of Otosaka and Kobayashi was "Higher levels of sedimentary radiocesium in the shallow regions are attributable to a higher contact probability of dissolved radiocesium with sediment as well as the efficient vertical transport of radiocesium to the deeper layer of sediment via bioturbation". They estimated amounts of dissolved and particulate ^{137}Cs transported southward to their study area (coastal part of north Ibaraki) using available surface seawater data (4th–5th paragraphs in their Discussion section). Their estimated results indicated that lateral flux of dissolved ^{137}Cs in the seawater was dominant, rather than that of the particulate phase. Hence, they reached the aforementioned conclusion. However, they did not discuss the sedimentation process of horizontally transported dissolved ^{137}Cs from surface seawater to the seabed. We believe that the ^{137}Cs downward transport likely included adsorption on particulate matter, which was suspended from the seabed in their study area and subsequently sank. The direct adsorption of dissolved ^{137}Cs on sediment as described by the referee also occurred in their study area, because surface and bottom seawater can be easily mixed by oceanic turbulence in shallow regions, as shown in Fig. 12b of our manuscript. However, in the hotspot swath of our target area offshore of the shelf break (50–100 m depths), our simulation indicated that the dissolved-^{137}Cs transported horizontally from the shallow region did not reach the bottom by vertical mixing as shown in Fig. 12g. There, horizontal transport of particulate ^{137}Cs suspended from the shallow seabed was likely dominant for ^{137}Cs sedimentation, as described in Sect. 4.3 of our paper (in which we added a similar sentence as section Revision #3-2). Indeed, from their observations, Otosaka and Kobayashi (2013) also reached the conclusion (their 4th) that "resuspension and lateral transport of the fine-grained sediments plays an important role to redistribute the sedimentary radiocesium".

As pointed out by the referee, we also think that the total amount of sedimentary ^{137}Cs should be more quantitatively validated. We could not do so adequately, although we attempted to validate by comparison between simulated and observed vertical sedimentary ^{137}Cs profiles, as mentioned in

Sect. 3.3. One of the reasons was a lack of observations after the accident in deeper sediment as required for the validation, especially near 1FNPP where massive sedimentary ^{137}Cs remains even today. Regarding the sediment trap measurements of Honda et al. (2013) and Buesseler et al. (2015) as described by the referee, their sites were unfortunately far offshore, outside our target area. Another reason why we could not validate was uncertainty related to our simulation conditions. As mentioned in Sect. 2.4, because we used the ideal sediment assumption, our simulation would overestimate sedimentary suspension unless the actual seabed consisted mainly of fine particles. In addition, our results had uncertainty regarding ^{137}Cs inflow conditions, especially atmospheric deposition. This is described in Sect. 2.2 of our revised manuscript, per the response to a comment by Reviewer #2. Clearly, the total amount of sedimentary ^{137}Cs directly depends on that of ^{137}Cs inflow.

We believe that the aforementioned quantitative uncertainty in our results should be described briefly and more clearly. Hence, we revised the manuscript (abstract, discussion, and conclusions, and other text) as in section Revision #3-3. In particular, because the total amount of sedimentary ^{137}Cs involves relatively great uncertainty, its description in the abstract has been deleted. We have substantially revised Sect. 4.1 to state that our result of total sedimentary ^{137}Cs amount has uncertainty.

Although our simulation contains the aforementioned quantitative uncertainties, we believe that sequential ocean dynamic processes of ^{137}Cs accumulation in the hotspot swath (as described in the first paragraph of Sect. 4.4) are at least qualitatively reasonable. This is because ^{137}Cs accumulation in that swath is mainly governed by ocean dynamics, i.e., spatiotemporal variation of bottom shear stress. That is, the quantitative uncertainty in simulation conditions would affect amounts of suspension and subsequent horizontal transport of sedimentary ^{137}Cs on the shallow shelf, but not the ^{137}Cs accumulation location offshore. Besides, our simulation reproduced several sedimentary ^{137}Cs characteristics found in the observations, indicating new reasonable findings of the causative ocean dynamics, i.e., the spring-neap tidal variation decreases the sediment-surface ^{137}Cs in the nearshore region (as described in Sect. 4.2). These have been described in the discussion and conclusions of the revised manuscript, as in the section Revision #3-3 below.

[Revision #2-1] (bold type shows revised sentences)
(P. 12729 L1 – P. 12730 L6, Sect. 3.1)
3.1 Seawater ^{137}Cs dispersion
To investigate **performance** of the seawater ^{137}Cs model, simulated ^{137}Cs activities on the sea surface (= $C_d + mC_p$; however, the sea-surface mC_p was negligible) were compared with observed data. For this comparison, we used TEPCO monitoring data (TEPCO, 2011) at the nearshore sites shown in Fig. 4j, where time series were sufficient. Observations at stations W-1 and W-2 were within the same simulation grid (Fig. 4a and j), because they are very close.

Sea-surface ^{137}Cs simulated by **the** model **largely** agreed with observed data (Figs. 4 and S2). The average *FA2* at all stations, which had a relatively large value of 52.2%, also indicates good model performance (Table S1). This agreement was **mainly** attributable to adjustment of the amount of ^{137}Cs inflow through atmosphere deposition and direct discharge from 1FNPP (mentioned in Sect. 2.3). However, all *FB* values in Table S1 became negative, indicating that the simulations still somewhat underestimated the sea-surface ^{137}Cs. **In particular, relatively large discrepancies between the simulations and observations were found in the initial period between the end of March and mid-April (Fig. 4). These discrepancies would affect initial ^{137}Cs sedimentation in the simulation. The results imply that the amount of actual ^{137}Cs inflow exceeded that input to the simulation.**

Spatiotemporal variation in sea-surface ^{137}Cs strongly depended on atmospheric deposition prior to the end of March, and afterward on direct discharge from 1FNPP (Figs. 3 and 4). Early in April, seawater ^{137}Cs reached a peak $O(10^3$–$10^4)$ Bq L^{-1} along the coast near 1FNPP (Fig. 4a–c) and $O(10^2)$ Bq L^{-1} 15 km offshore (Fig. 4d–i). There was a rapid decline of activity from mid-April to beginning of May, and a gradual decrease afterward (Fig. 4a–i). The decrease in seawater ^{137}Cs was caused by significant dispersion from the coastal region to the open ocean (Fig. S2). As mentioned in Sect. 1, many studies have discussed the spatiotemporal ^{137}Cs distribution and its **detailed** physical background **on the basis of numerical simulations** (Kawamura et al., 2011; Tsumune et al., 2012, 2013; Masumoto et al., 2012; Choi et al., 2013; Miyazawa et al., 2012, 2013). **Hence, we do not address the seawater ^{137}Cs in detail hereafter. It stands to reason that there was no earlier simulation that quantitatively agreed with our spatiotemporal distribution of seawater ^{137}Cs, because of differences in numerical procedures and/or simulation conditions. Thus, we confirmed that our seawater ^{137}Cs dispersion (Figs. 4 and S2) had qualitative features similar to the earlier simulations. For instance, our simulation tended to underestimate sea-surface ^{137}Cs southeast of 1FNPP, such as at stations W-8 through W-10 (Fig. 4g–i, and *FB* in Table S1) per the earlier simulations (Kawamura et al., 2011; Tsumune et al., 2012; Miyazawa et al., 2013).**

[Revision #2-2] (bold type shows revised sentences)
(P. 12724, L1 – L29, Sect. 2.2)
Inflow conditions of the dissolved ^{137}Cs, particulate ^{137}Cs, and suspended particulate matter must be given at the sea-surface boundary in Eqs. (1)–(3), respectively. We considered the ^{137}Cs inflow through two pathways, direct discharge from 1FNPP and atmospheric deposition. We treated both inflow ^{137}Cs as in the dissolved phase. These source data were referred to **Tsumune et al. (2012)** for time series of direct discharge from 1FNPP **(total of 3.5 PBq until the end of May 2011)**, and Morino et al. (2011) for spatiotemporal variation in atmospheric deposition, simulated by an atmospheric chemical-transport model **(total 2.3/1.5 PBq in Region 1/2 through the end of April 2011)**. However, our preliminary experiments using these data indicated that simulated ^{137}Cs

activities, **especially in surface seawater**, were **much** less than observed in all of Region 2, **such that both sources were believed** to be underestimated overall. **In fact, these amounts were much smaller than a recent evaluation by Miyazawa et al. (2013) (direct discharge: 5.5–5.9 PBq through 6 May 2011, atmospheric deposition: 5.5–9.7 PBq within 12°–62°N and 108–180°E through 6 May 2011). Although their estimation was based on comparison between seawater surface** ^{137}**Cs in their ocean-atmosphere simulations and that of field observations, their oceanic** ^{137}**Cs dispersion model did not include** ^{137}**Cs adsorption on suspended particulate matter and subsequent** ^{137}**Cs sinking in seawater. If downward transport was not negligible, their estimation should increase. Furthermore, spatiotemporal variation of atmospheric** ^{137}**Cs deposition over the ocean, which has been estimated by numerical simulations in several studies besides Miyazawa et al. (2013) and Morino et al. (2011), had relatively great uncertainty. These total depositions also had wide variation (e.g., 5 PBq within 30.5°–48.0°N, 127.0°–154.5°E through the end of April, Kawamura et al., 2011; 7.6 PBq in the North Pacific through the end of April, Kobayashi et al., 2013; 28 PBq in the oceans through 20 April, Stohl et al., 2012). This difference may principally be caused by the source parameter of 137Cs emission from 1FNPP to atmosphere (e.g., 8.8 PBq, Terada et al., 2012; 13 PBq, Chino et al., 2011, 35.9 PBq, Stohl et al., 2012) and wet/dry deposition schemes (e.g., Stohl et al., 2012). The present simulation used source data that were 1.65 times the direct discharge from 1FNPP of Tsumune et al. (2012) and 6.00 times the atmospheric deposition of Morino et al. (2011) (Fig. 3a).** As a result, total direct discharge was 5.9 PBq through the end of May. Total atmospheric deposition on the sea surface was 13.8/9.2 PBq in Region 1/2 through the end of April. **Although this simple scaling reduced the discrepancy between observed and simulated seawater surface** ^{137}**Cs, we could not validate the** ^{137}**Cs inflow conditions in detail because neither the direct discharge nor the atmospheric deposition can be measured directly.**

We ignored 137Cs loading from the land as a source because its amount, which has been estimated at 0.0075 PBq **of** ^{134}**Cs, is regarded as nearly equivalent to the** ^{137}**Cs amount** through the end of October 2011 (Otosaka and Kato, 2014**). This** was much smaller than that of the direct discharge and atmospheric deposition. We also neglected particulate matter loading from the land, because of a lack of available data. This may impose some limitation on our simulation, because the validity of that neglect is not well known.

References (additional)
Chino, M., Nakayama, H., Nagai, H., Terada, H., Katata, G., and Yamazawa, H.: Preliminary estimation of release amounts of ^{131}I and ^{137}Cs accidentally discharged from the Fukushima daiichi nuclear power plant into the atmosphere, J. Nucl. Sci. Technol., 48, 1129–1134, 2011.

Kobayashi, T., Nagai, H., Chino, M., and Kawamura, H.: Source term estimation of atmospheric release due to the Fukushima Daiichi Nuclear Power Plant accident by atmospheric and oceanic

dispersion simulations, J. Nucl. Sci. Technol., 50, 255-264, doi:10.1080/00223131.2013.772449, 2013.

Stohl, A., Seibert, P., Wotawa, G., Arnold, D., Burkhart, J. F., Eckhardt, S., Tapia, C., Vargas, A., and Yasunari, T. J.: Xenon-133 and caesium-137 releases into the atmosphere from the Fukushima Dai-ichi nuclear power plant: determination of the source term, atmospheric dispersion, and deposition, Atmos. Chem. Phys., 12, 2313–2343, doi:10.5194/acp-12-2313-2012, 2012.

Terada, H., Katata, G., Chino, M., and H. Nagai: Atmospheric discharge and dispersion of radionuclides during the Fukushima Dai-ichi Nuclear Power Plant accident. Part II: verification of the source term and analysis of regional-scale atmospheric dispersion, J. Environ. Radioactiv., 112, 141–154, 2012.

[Revision #3-1] (bold type shows revised sentences)
(P. 12725, L1 – L5, Sect. 2.3)
At the bottom boundaries in the seawater ^{137}Cs simulation, **diffusion flux of the dissolved ^{137}Cs and** sedimentation/suspension fluxes of the particulate ^{137}Cs and suspended particulate matter, which were evaluated by the sediment ^{137}Cs model described in Sect. 2.4, were specified. At the lateral boundaries, the three variables in the Region-1 simulation were set to zero. We used the hourly Region-1 results in the Region-2 domain.

(P. 12728, L4 – L13, Sect. 2.4)
Net flux of particulate ^{137}Cs evaluated from Eqs. (12) and (13) was given as the surface seabed condition of Eq. (6) and bottom boundary of Eq. (2). Similarly, net flux of particulate matter from Eqs. (9) and (10) was specified at the bottom boundary in Eq. (3). Exchange of dissolved ^{137}Cs between bottom seawater (Eq. (1)) and surface seabed (Eq. (5)) was calculated from the diffusion equation. The diffusion coefficient was derived from bottom seawater turbulent and sedimentary bioturbation. Adsorption of dissolved ^{137}Cs in bottom seawater on surface sediment may occur through the diffusion process in our model. At the bottom boundaries of Eqs. (5) and (6), we specified flux conditions as advection-outflow at the sedimentation, or zero-inflow at the suspension if deeper ^{137}Cs activity was assumed zero. These fluxes were consistent with mass balance of the particulate matter expressed by the identical Eq. (7). However, there is an issue in the method, in that Eq. (7) cannot be restricted to the suspended amount of sediment matter, i.e., it is possible that the fine particulate matter is infinitely and endlessly supplied from deeper levels. Therefore, the present procedure using the relative vertical-axis z' and uniform sediment assumption, which facilitates simulation of the vertical profile of sedimentary ^{137}Cs, probably overestimates the suspension in regions whose seabed does not actually have sufficient suspendable particulate matter.

[Revision #3-2] (bold type shows revised sentences)

(P. 12737, L16 – L28, Sect. 4.3)

In contrast to the shallow region, in the offshore region along the shelf break (50–200 m depths), impacts of the tide and strong wind on the bottom disturbance were much weaker (<50 m depths). Even the extratropical cyclone that caused the strong bottom disturbance in the shallow region at the end of May could not increase bottom friction beyond the critical shear stress (Figs. 10c and 12f), so little sediment was suspended (Figs. 11c and 12h). **Although strong vertical mixing then occurred in seawater, dissolved ^{137}Cs activity in bottom seawater did not increase (Fig. 12g), in contrast to the shallow result (Fig. 12b).** Nevertheless, sedimentary ^{137}Cs activities in the offshore region began to increase significantly just after that strong wind event (MEXT stations C3, E1, D1, G0, G1, I0, I1, J1 in Fig. 6, and E1 in Fig. 12j). This increase in sedimentary ^{137}Cs resulted from sedimentation of particulate ^{137}Cs (Fig. 12i), which was suspended and horizontally transported into and from the adjacent shallow shelf by the wind event. This horizontal transport is supported by the fact that both concentrations of suspended matter and particulate ^{137}Cs suddenly increased in the upper seawater, without bottom suspension or upward diffusion (Fig. 12h and i).

[Revision #3-3] (bold type shows revised sentences.)

(P. 12715, L3 – L9, Abstract)

(**The 3rd paragraph in the Abstract was deleted**)

(P. 12718, L17 – P. 12719, L10, Sect. 1)

Our previous study (Higashi et al., 2014) developed a comprehensive model for simulating oceanic ^{137}Cs behaviour in both seawater and seabed, with consideration of vertical ^{137}Cs transport in the sediment. We then roughly assumed that sediment matter in the entire simulation domain had ideal properties such as identical bulk density, uniform porosity, and particle aggregates of a single grain diameter. **The reason why we used this assumption was not only because spatiotemporal variation of sediment properties just after the tsunami disturbance was unknown but also because the assumption enabled direct simulation of vertical ^{137}Cs behaviour in the sediment.** This type of assumption has also been used in other models (Kobayashi et al., 2007; Choi et al., 2012), except for the ^{137}Cs behaviour in sediment. Our earlier simulations using the developed model agreed reasonably well with the sampling of ^{137}Cs activity in both seawater and sediment off east Japan in the Pacific during March and December 2011. However, we could not effectively simulate the heterogeneous sedimentary ^{137}Cs distribution, mainly because of a lack of spatial resolution.

We performed a downscaling simulation of oceanic ^{137}Cs behaviour using the usual one-way nesting method to resolve the heterogeneous sedimentary ^{137}Cs distribution, especially in the hotspot swath. **The present simulation also used the aforementioned assumption of ideal sediment properties in the entire domain, for the same reasons.** The model and the numerical procedure are described in Sect. 2. Simulated results of the spatiotemporal ^{137}Cs distributions in seawater and sediment within

the nested region are shown in Sect. 3 as compared with observations, **to evaluate model performance**. In Sect. 4, we discuss ocean dynamic processes causing the spatially heterogeneous distribution, especially in the hotspot swath, **and include model uncertainties.**

(P. 12733, L10 – P. 12734, L28, Sect. 4.1)

4.1 **Total amount of sedimentary ^{137}Cs and its uncertainty**

The total ^{137}Cs amount rapidly increased at the beginning of April in our simulation because of atmospheric deposition and direct discharge from 1FNPP (Fig. 3). After that, it stabilized at ~12 PBq by the end of May, and strongly declined to 4.3 PBq at the end of 2011. The latter decrease was caused by the seawater ^{137}Cs dispersed from Region-2 to the open ocean. Sedimentary ^{137}Cs also increased steadily until onset of the significant seawater dispersion, but suddenly declined at the end of May. This rapid decrease resulted from short but strong suspension induced by an extratropical cyclone that originated as typhoon 201102 (SONGDA) and passed over the southern part of Region-2. Afterward, the sedimentary ^{137}Cs rapidly recovered, indicating that the suspended ^{137}Cs returned to the sediment. **Such behaviours of sedimentary ^{137}Cs before and after the cyclone were also simulated by Choi et al. (2013).**

In our simulation, total sedimentary ^{137}Cs was 0.10 PBq (0.66% of total ^{137}Cs inflow) in the upper 3 cm layer, 0.40 PBq (2.6% of total ^{137}Cs inflow) in the upper 10 cm layer, and 3.2 PBq (21% of total ^{137}Cs inflow) in the entire seabed over all of Region 2 (1.4 × 10^5 km^2) at the end of 2011. Kusakabe et al. (2013) estimated 0.042–0.052 PBq of total sedimentary ^{137}Cs between September and December 2011 in the upper 3 cm seabed off Miyagi, Fukushima, and Ibaraki prefectures (2.2 × 10^4 km^2 domain) on the basis of the MEXT (2011) observations. Otosaka and Kato (2014) estimated total sedimentary ^{134}Cs. **This was regarded as nearly equivalent to ^{137}Cs amount** at 0.20 ± 0.06 PBq (decay-corrected to 11 March 2011) within the region less than 200 m depth (1.5 × 10^4 km^2 domain) in October 2011, using **their sampling data in upper 10 cm sediments and MEXT observations. Accounting for the difference in study area, our results of sedimentary ^{137}Cs amounts in the upper layers were almost comparable to the two studies above. However, the simulated amounts in the upper 3 and 10 cm layers were only 3% and 13% of total sedimentary ^{137}Cs, respectively; the remainder was present in deeper sediment.**

We could not adequately validate the simulated result of large ^{137}Cs amount in the deeper layers. One of the reasons was a lack of observations in deeper sediment, necessary for validation after the accident, especially near 1FNPP where massive sedimentary ^{137}Cs remains even today (described in Sect. 3.3). We described in Sect. 3.2 that the simulated concentrations of sediment-surface ^{137}Cs were roughly comparable with observations, except for overestimation to the northeast of 1FNPP. However, this agreement could not validate ^{137}Cs migration flux from seawater to sediment. The insufficiency of deeper data was also the reason why the earlier estimations of total sedimentary ^{137}Cs might be underestimated as described by their authors (Kusakabe et al., 2013; Otosaka and Kato, 2014). Indeed, recent surveys have

detected high activity $O(10^3$–$10^4)$ Bq kg^{-1} $(=O(10^6$–$10^7)$ Bq m$^{-3})$ through the present, in both surface and lower (> 30 cm) sediment at several sampling stations near 1FNPP (Thornton et al., 2013; NRA, 2014a). Our simulation also revealed 1.0 PBq **(31% of total sedimentary ^{137}Cs)** in a large amount of sedimentary ^{137}Cs in the 30 × 30 km square domain (140.88°–141.21°E, 37.29°–37.56°N in Fig. 9, **except for the land**) around 1FNPP at the end of 2011.

Another reason why we could not validate the sedimentary ^{137}Cs amount in the deeper layer was uncertainty related to our simulation conditions. As mentioned in Sect. 2.4, because we used the ideal sediment assumption, our simulation would overestimate sedimentary suspension unless the actual seabed consisted mainly of fine particles. In fact, that simulation overestimated some sediment-surface ^{137}Cs activities to the northeast of 1FNPP and Sendai Bay, whose seabed was dominated by coarse sand (mentioned in Sect. 3.2). The simulated amount of sedimentary ^{137}Cs in the 30 × 45 km rectangular region in Sendai Bay (141.03°–141.37°E, 37.71°–38.11°N in Fig. 9) reached 0.52 PBq **(16% of total sedimentary ^{137}Cs). Furthermore, our result included uncertainty of ^{137}Cs inflow conditions, especially the atmospheric deposition (Sect. 2.2). Clearly, the total amount of sedimentary ^{137}Cs directly depends on that of ^{137}Cs inflow.**

(P. 12737, L1 – L14, Sect. 4.2)
The bottom disturbance caused by the tide or strong wind did not occur in every shallow region (< 50 m depths) because of the seabed topography and other factors. In the narrow nearshore region from south Fukushima to north Ibaraki, bottom friction did not increase even during extratropical cyclone passage (Fig. 10c). The Otosaka and Kobayashi (2013) station O-S4, where apparent downward movement of **sedimentary** ^{137}Cs was found in both observation and simulation (Fig. 8i), was located just in that region. This area was where the bottom disturbance rarely occurred; if anything, the sedimentation slightly dominated the suspension over a long period (Fig. 11d). This indicates that the apparent vertical transport of **sedimentary** ^{137}Cs found at station O-S4 was caused by relatively fresh suspended particulate matter settling on earlier sediment containing substantial ^{137}Cs. It is inconceivable that the amount of sedimentation over only several months became so large under the stable seabed condition. **Although this is probably caused by the uncertainty related to the ideal sediment assumption as mentioned in Sect. 4.1,** this may have been possible in the unstable **seabed** state just after the extraordinary disturbance of the tsunami.

(P. 12738, L11 – L24, Sect. 4.4)
The hotspot swath in our simulation was just offshore of the shelf break (along the 50–100 m isobath) off southern Fukushima Prefecture through northern Sendai Bay at the end of 2011 (Fig. 5j). After the 1FNPP accident, the region of high sedimentary ^{137}Cs activity gradually expanded from south of 1FNPP to north in and around the shelf (< 100 m depths) by June (Fig. 5a–e). Afterward, in the shallow shelf (< 50 m depths), the sediment-surface ^{137}Cs significantly decreased because of the

periodic tidal disturbance causing sediment suspension, horizontal transport in the seawater, and/or apparent downward movement in the seabed. Meanwhile, in the offshore region (50–100 m depths), the sedimentary ^{137}Cs that settled after being horizontally transported from the shallow region during the extratropical cyclone at the end of May remained largely stable, because of rare bottom disturbance. The present simulation suggests that these were the sequential processes causing the hotspot swath, and that its shape is closely related to spatiotemporal variation between bottom shear stress on the shallow shelf and that offshore of the shelf break. **Although our simulation includes quantitative uncertainty as mentioned in Sect. 4.1, these processes are at least qualitatively reasonable. This is because ^{137}Cs accumulation in the hotspot swath is governed mainly by ocean dynamics, i.e., spatiotemporal variation of bottom shear stress. That is, the quantitative uncertainty in simulation conditions would affect amounts of suspension and subsequent horizontal transport of sedimentary ^{137}Cs on the shallow shelf, but not the ^{137}Cs accumulation location offshore.**

(P. 12739, L9 – L14, Sect. 5)

To clarify ocean dynamic processes causing the massive heterogeneous sedimentary ^{137}Cs distribution that persists in and around the shelf off Fukushima and adjacent prefectures, we numerically simulated oceanic ^{137}Cs behaviour for about 10 months after the 1FNPP accident. We succeeded in simulating that distribution, especially the hotspot swath just offshore of the shelf break (along the 50–100 m isobath) shown by recent observations (Thornton et al., 2013; Ambe et al. 2014; NRA, 2014a). **However, quantitative validation of sedimentary ^{137}Cs amount was inadequate. The result suggests that several spatiotemporal characteristics of the sedimentary ^{137}Cs is produced by ocean dynamics.**

(P. 12740, L5 – L25, Sect. 5)

Our simulation also produced significant findings regarding sedimentary ^{137}Cs behaviour on the shallow shelf. There, the simulated bottom disturbance tended to occur frequently because of the periodic spring tide and occasional strong winds, steadily decreasing simulated sediment-surface ^{137}Cs per several observations. The simulation indicated that repeated bottom disturbances reducing sediment-surface ^{137}Cs over the long term caused sedimentary ^{137}Cs to not only be horizontally transported to the offshore region but also vertically toward deeper sediment. Consequently, in our simulation, relatively large amounts of ^{137}Cs in deeper sediment remained on the shallow shelf, especially near 1FNPP, even about 10 months after the 1FNPP accident. Hence, **total sedimentary ^{137}Cs at the end of 2011 reached 3.2 PBq, and 87% of that was present below the 10 cm layer.** If our simulation is correct, ^{137}Cs in deeper sediment would be much greater than in upper sediment, and would remain stable over a long period. **However, the simulated sedimentary ^{137}Cs amount in the deeper layers would include relatively large uncertainty at present. In future work, we will improve the model for quantitative simulation of the spatiotemporal variation of fine**

particulate matter in both seawater and sediment. We will perform long-term simulations including the tsunami disturbance to validate the model, using recent observations of vertical sedimentary ^{137}Cs distribution.

[Other revision]
We corrected writing errors of value of E in Table 1 and of a legend in Fig. 12c.