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Biogeosciences
Discussions

Interactive comment on "Initial Spread of ^{137}Cs over the shelf of Japan: a study using the high-resolution global-coastal nesting ocean model" *by* Z. Lai et al.

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General Comments

"This study conducted a numerical simulation of 137Cs released from the Fukushima Dai-ichi nuclear power plants using a high resolution FVCOM model. The results showed that the high resolution model is better than those coarse resolution models operated in previous studies to capture the initial spread of 137Cs. The topic is of interest. I have a few concerns and hope they can be clarified before publication of this manuscript."

Answer: We have carefully read the reviewer's comments. The main concerns regarding the source point of 137Cs inside the seawall structure of the power plant were raised with being unfamiliar with what really happened for accident. We have added a reference to provide a more clear explanation for the setup of our experiments and to avoid confusions that could be easily caused due to the lack of the details. See the details below for our responses.

Specific comments

"The most important finding of this study is that the source point of 137Cs is critical to resolve the dispersion process. In front of the nuclear plant, there is a seawall structure. The power plant intakes water from inside of the seawall structure and discharges water outside the seawall structure on the north and south sides (namely, the north and south discharging canals), respectively. The two discharging canals were considered the point sources of the release of 137Cs (Tsumune et al, 2012; Estournel et al., 2012). In this study, however, the discharge point of 137Cs is located inside the seawall structure (Figures 2 and 7), rather than at the two discharging canals. It seems that this treatment of source point allows 137Cs to disperse farther seaward such that the modeled 137Cs concentrations match the measurements at the MEXT stations better than the previous studies. My concern is whether this setup of the source of 137Cs is reasonable, and I hope this can be confirmed by someone who is familiar with the study site."

Answer: Several reports clearly show that instead of through the two discharge canals, the majority of the 137Cs released to the ocean since April 2011 occurred inside the seawall structure. The high-level radioactive water were mainly from leaking from the Unit 2 and Unit 3 reactors during April through May, 2011, while the south discharge canal only contained the low-level waste water with a total amount of released 137Cs 2 - 4 orders of magnitude smaller. An example of the detailed information can be found in TEPCO press release on April 6 2011 posted at the web address: http://www.tepco.co.jp/en/press/corp-com/release/11040601-e.html). This press release clearly stated that that the major releases of 137Cs from Unit 2 and Unit 3 re-

actors were at the intake channel of the units, which are located inside the seawall structure. This can be confirmed from the comprehensive reviewing paper by Ohnishi (2012). Figure 15 in his paper suggests that the leakage of highly contaminated water at the intake channel of Unit 2 actually started earlier in March.

By resolving the realistic geometry of the FNPP, our high-resolution experiment was made by resolving the detailed water exchange process between the FNPP and adjacent coastal ocean. The outflow of the high-contaminated water, after leaking into the water inside the FNPP, will be carried by the local complex flow field, rather than outflow at the two discharge canals. Therefore, releasing all of the 137Cs only at the two discharge canals is not realistic. Actually, Tsumune et al (2012) admitted that the largest direct release of 137Cs to the ocean was observed near the water intake of the Unit 2 reactor (see the introduction of their paper). Estournel et al. (2012) even explicitly stated that “Such a simple grid geometry does not match the reality of the situation as radioactive leaks were detected inside the area delimited by the seawalls and not at the outlets.”. Because the model resolution used in their experiments was too coarse to resolve the detailed structure of the seawall and discern between the source point and the two discharge canals, they could only treat the sources as fixed point sources. The along-shore dimension of the breakwater structure is 1.3 km. The model grids used in Tsumune et al. (2012) and Estournel et al. (2012) were 2.0 km, and 0.6 km, respectively. These resolutions were not sufficient to resolve the flow field inside the two breakwaters.

We have significantly revised the manuscript with a more clear description of the release process used in our experiments for the cases with and without resolving the FNPP. Our experiments for the case without resolving FNPP had the same setup as Tsumune et al. (2012) and Estournel et al. (2012). An emphasis was placed on explaining the dispersive and advective processes that control the spread of 137Cs. We have attached the revised manuscript online to provide the reviewer with the detailed information about the changes we have made.

"Because the source term of 137Cs is determined by the inverse method, this study as well as the previous work (Kawamura et al., 2011; Tsumune et al, 2012; Estournel et al., 2012) can obtain reliable results near the power plant. This study further improved the results at MEXT stations, but still has relative large discrepancies between model and observation at the WHOI stations (Figures 10 and 11, and notice the log scale). Does this indicate that the high resolution grid actually didn’t help improve much of the prediction, and the improvement at the MEXT sites merely comes from the setup of the source point of 137Cs?"

Answer: The large discrepancies of 137Cs concentration between model-computed and observed 137Cs concentrations at the WHOI stations in June, 2011 were due to the other physical processes that were not considered in our mass-conservative tracer tracking experiments. The model-data comparison clearly showed that the model-computed 137Cs concentration was overestimated at the surface but underestimated near the bottom. This fact implies that there were other physical processes that were responsible for a downward flux of 137Cs in the water column. By adding a sinking term in the 137Cs concentrations tracer model, one should be able to improve the simulation results. Such a sinking term is related to sedimentation over the shelf with the sinking velocity varying significantly with different types of sediment. Our finding was also anticipated by Estournel et al. (2012) who suggested that an overestimation of the predicted 137Cs concentration can probably be caused by ignoring a sinking term in the tracer equation. The suggestions from the modeling experiments are supported by the 137Cs concentration levels found in the bottom sediment layer at monitoring sites along the Japanese coast. At many monitoring sites in the shelf region between the 50-m and 200-m isobaths, the observed 137Cs concentration in sediments increased significant with time. In monitoring sites around FNPP, the sediment 137Cs concentrations showed high values before July and then decreased rapidly with time afterward. A simple estimation indicates that during April-June, the model-data discrepancy values at the surface and near the bottom were about 48% and -39% in the coastal area. So, without adding a sinking term in the 137Cs tracer equation, about 9% more of the

total amount of 137Cs remained in the seawater than what was measured. Assuming these extra amounts were deposited in the sediment through sedimentation, this means that at least 9% of the discharged 137Cs were removed by sedimentation. The rapid drop in 137Cs concentrations at monitoring sites in the coastal region around FNPP after July implies that the 137Cs in sediment layers could be re-suspended and carried offshore through advection and mixing processes. This can be inferred since the observation data showed that the concentration of radioactive materials through the end of July remained higher than expected in the coastal region (Buesseler et al., 2012). Because these processes varied significantly in space and time and the lack of knowledge about the 137Cs-sediment flocculation processes, it was not feasible to attempt to include sedimentation in our 137Cs tracking experiments.

Our modeling results clearly demonstrated that the initial spread of 137Cs was controlled by advective and lateral dispersive processes that not only depend on model grid resolution but geometric fitting. This explains why a high-resolution model with resolving the geometry of FNPP was capable of improving the prediction of 137Cs at the MEXT sites. As the 137Cs plume spread into the stratified offshore region, in addition of vertical sedimentation process described above, the advection and vertical/lateral mixing becomes more critical. Chen et al. (2008) derived analytically the governing equations controlling the movement of the center of a small-scale dye patch in the coastal ocean. The equations indicate that after the dye is released, the movement of the dye patch is driven by the ensemble velocity integrated through the dye patch and the concentration flux related to the vertical shear of the horizontal velocity of the dye patch. Considering a dye patch that moves conservatively in the ocean, the total amount of the dye remains unchanged, but its concentration can change significantly as a result of deformation of the dye patch due to vertical and lateral dispersion that are related to velocity shears and turbulent diffusion. In order to capture the dye spreading, it is critical to resolve the realistic vertical and lateral diffusion processes. For many coastal ocean models, the horizontal diffusion is parameterized using a Smagorinsky eddy parameterization method (Smagorinsky, 1963), which depends on the model res-

olution and velocity shears. Our results indicate that an underestimation of 137Cs concentration over the shelf predicted by Global-FVCOM was mainly due to the overestimation of 137Cs spreading in the coastal region. This overestimation was caused by insufficient grid resolution to capture realistic lateral diffusion. This explanation can be applied to previous regional model simulations and emphasize the critical importance of model resolution in the parameterization of lateral diffusion. Therefore, the high-resolution grid does help improve the simulation of advection and dispersion processes that can directly affect the simulation accuracy of 137Cs concentration.

We have significantly revised our manuscript with inclusion of a detailed analysis of the dynamical reasons for the overestimation. To help the reviewer view what we have revised, we have attached a revised manuscript in our reply. Please see the section 3.1 for model-data comparison and section 4 for discussion in the revised manuscript.

"Even though this is a short paper, providing some details of the inverse method might help understand the model results if it is not exactly the same as that of Tsumune et al. (2012). For example, the initial 137Cs concentration, the volume of water in which 137Cs was released, and the estimated release rate of 137Cs, etc."

Answer: After the paper was submitted, we have revised the text to improve the model-data comparison and add the dynamical analysis and explanation. An additional section was added to compare the results between high-and coarse-resolution models with an emphasis on why grid resolution and geometric fitting are so important to resolve the advection and dispersion processes. These revisions have added much critical information that improves the manuscript (for which we thank the reviewer) but has also made it longer. Following the reviewer's suggestion, we also provided an explanation about the key differences between our and previous (such as Tsumune et al., 2012) modeling approaches. See the revised manuscript in the attachment.

"Please add legends in Figures 4, 10, and 12."

Answer: Added.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/10/C1391/2013/bgd-10-C1391-2013-supplement.pdf

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