



## Spatial and temporal variations and budget of radiocesium in the ocean following the Fukushima Daiichi Nuclear Power Plant accident

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A series of accidents at the Fukushima Dai-ichi Nuclear Power Plant following the earthquake and tsunami of 11 March 2011 resulted in the release of radioactive materials to the ocean by two major pathways, direct release from the accident site and atmospheric deposition. We determined the inventory of radiocesium released by the TEPCO Fukushima Dai-ichi Nuclear Power Plant (FNPP1) accident to the North Pacific Ocean based on measurements of seawater samples collected in the North Pacific Ocean after the accident. Comparison of the observed inventory with the model-simulated results allowed us to obtain realistic values of 10–13 PBq for the total atmospheric deposition of  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  released by the FNPP1 accident in the North Pacific. Before the Fukushima accident,  $^{137}\text{Cs}$  inventory in the North Pacific Ocean was about 69 PBq, the 12–15 PBq of  $^{137}\text{Cs}$  newly added by atmospheric deposition and the  $3.5 \pm 0.7$  PBq added by direct discharge, therefore increased the total  $^{137}\text{Cs}$  inventory in the North Pacific Ocean by 22–27 %. We also determined that the total atmospheric release of  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  by the FNPP1 accident was about 14–17 PBq, respectively.

Using global simulated results as boundary conditions, a 1-year, regional-scale simulation of  $^{137}\text{Cs}$  activity in the ocean offshore of Fukushima was also carried out, the sources of radioactivity being direct release, atmospheric deposition, and the inflow of  $^{137}\text{Cs}$  deposited on the ocean by atmospheric deposition outside the domain of the model. The contributions of each source were estimated by analysis of  $^{131}\text{I}/^{137}\text{Cs}$  and  $^{134}\text{Cs}/^{137}\text{Cs}$  activity ratios and comparisons between simulated results and measured activities of  $^{137}\text{Cs}$ . Simulated  $^{137}\text{Cs}$  activities attributable to direct release were in good agreement with measured activities close to the accident site, a result that implies that the estimated direct release rate was reasonable, while simulated  $^{137}\text{Cs}$  activities attributable to atmospheric deposition were low compared to measured activities. The rate of atmospheric deposition onto the ocean was underestimated because of a lack of measurements of deposition onto the ocean when atmospheric deposition rates were being estimated. Measured  $^{137}\text{Cs}$  activities attributable to atmospheric deposition helped to improve the accuracy of simulated atmospheric deposition rates. Simulated  $^{137}\text{Cs}$  activities attributable to the inflow of  $^{137}\text{Cs}$  deposited onto the ocean outside the domain of the model were in good agreement with measured activities in the open ocean within the model domain after June 2012. The contribution of inflow increased with time and was dominant (more than 99 %) by the end of February 2012. The activity of directly released  $^{137}\text{Cs}$ , however, decreased exponentially with time and was detectable only in the coastal zone by the end of February 2012.