NUMERICAL ANALYSIS FOR ^{137}CS ON SEABED SEDIMENT INCLUDING ATMOSPHERIC DEPOSITION NEAR THE FUKUSHIMA COASTAL AREA

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Abstract: Radionuclides were released into the atmosphere and ocean from the accident at the Fukushima Daiichi Nuclear Power Plant (NPP) in March 2011. Numerical simulations were performed to evaluate the distribution of ^{137}Cs in the ocean with considering directly release and deposition from the atmosphere. Calculated concentrations of ^{137}Cs in the sea water and seabed are compared with the measured data, and atmospheric transport model has been also used to calculate the rates of atmospheric deposition on the sea surface. Lots of atmospheric deposition was occurred on sea surface in northeast direction from Fukushima NPP due to westerly wind and precipitation on March 15-31, 2011. Most modelling for the marine dispersion of ^{137}Cs after Fukushima accident was considered as a perfectly conservative radionuclide, thus scavenging processes and adsorption on seabed sediments are neglected. The processes of the non-conservative from the numerical simulations have been well described and the calculated results are also in agreement with the measured data. The concentrations of ^{137}Cs in seabed sediments were mainly contributed by the atmospheric deposition and long residence time showed in northeast coastal area off Fukushima NPP.

Key words: numerical simulation, direct release, atmospheric deposition

INTRODUCTION

In March 2011, a nuclear accident was occurred by the Tohoku earthquake and tsunami at the Fukushima Daiichi nuclear power plant (NPP). A lot of radioactive material by the accident was released into the atmosphere and ocean. Unlike the Chernobyl incident, long-term impact from radioactive materials released into the sea should be taken into account to investigate the direct or indirect effects on the marine environment, marine resources and human health.

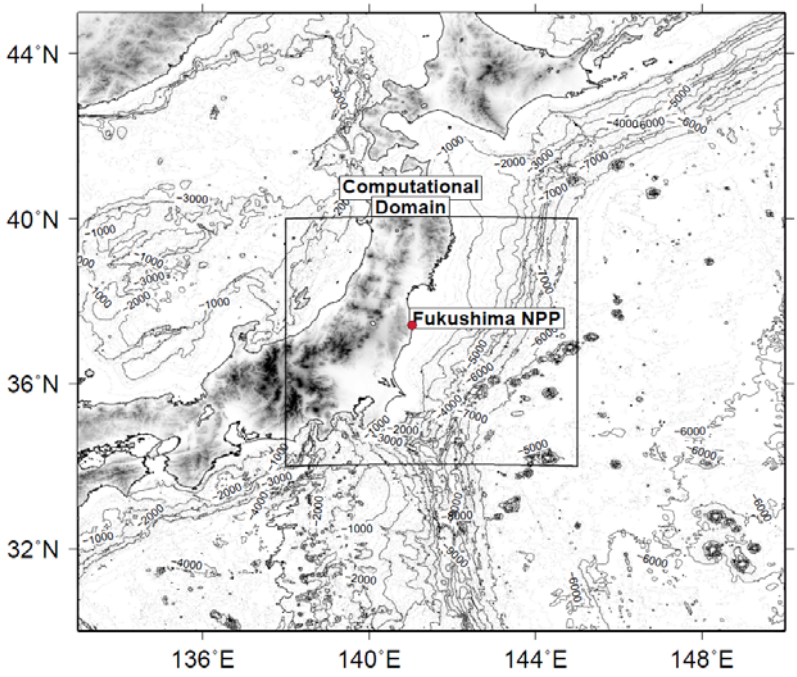

Figure 1. Computational domains for the numerical simulation of the concentration of 137Cs on seabed sediment

After the Fukushima accident, many studies have been performed to investigate the dispersion patterns of ^{137}Cs in the ocean by numerical experiments. Studies concerning marine dispersion modelling of ^{137}Cs have carried out using each other conditions such as computational domain, horizontal and vertical resolutions, hydrodynamics, with and without atmospheric deposition (Tsumune et al., 2012; Masumoto et al., 2012; Kawamura et al., 2011; Honda et al., 2012; Perianez et al., 2012; Nakano et al. 2012). It is common to all developed models to consider ^{137}Cs as a perfectly conservative radionuclide expect one model (Perianez et al., 2012), thus scavenging processes and adsorption on seabed sediments are neglected. Many researches (Bailly et al., 2012; Tsumune et al., 2012; Kawamura et al., 2011; Honda et al., 2012; Perianez et al., 2012) were also included in the effects of atmospheric deposition, but they had not shown the significant differences with and without it. Most modelling results in considering air fallout were put the constant fallout rate in the computational domain without in the time and space varying deposition term. Thus the modelling results did not find the significant differences in considering atmospheric deposition.

The objective of this paper is to analyze the dispersion of ^{137}Cs taking into account for water/sediment interactions using Lagrangian particle model for the regional scale around Fukushima sea. Also, the time and space varying aeolian deposition of ^{137}Cs is included in the model to investigate the variations of the concentration in the seawater and seabed sediments. Calculated concentrations of ^{137}Cs are compared with measurements in the seawater and seabed sediments. We mainly focus on ^{137}Cs distributions in seabed sediments, especially effect change of concentration on seabed sediments due to atmospheric deposition.

NUMERICAL EXPERIMENTS

The dispersion model based on the Lagrangian particle method has been developed by the authors and tested in different marine environments (Perianez, R. and A.J.M., Elliott, 2002; Perianez, R., 2004; Perianez, R., 2011) and a variety of atmospheric conditions (Suh et al., 2006; Suh et al., 2008; Suh et al., 2009). The oceanic circulation fields like tide, wind and density driven circulation were provided from JCOPE2 at the Japan Agency for Marine-Earth Science and Technology and atmospheric conditions like mixing height, precipitation and wind speed were provided from KMA (Korea Meteorological Administration) with horizontally 12km resolutions. Each model has named LORAS (Long-range Oceanic Radiological Assessment System) and LADAS (Long-range Accident Dose Assessment System). LADAS was designed to estimate air concentration and dry deposition as well as wet deposition at distances of up to some thousands of kilometers from a source point in a horizontal direction. Detailed mathematical descriptions of the atmospheric transport model (LADAS) may be seen in references (Suh et al., 2006; Suh et al., 2008; Suh et al., 2009). The calculated deposition rate of ^{137}Cs on the sea surface was presented with time function in computational domain (138.0º ~ 145.0º E, 34.0º ~ 40.0º N) in Fig. 1.

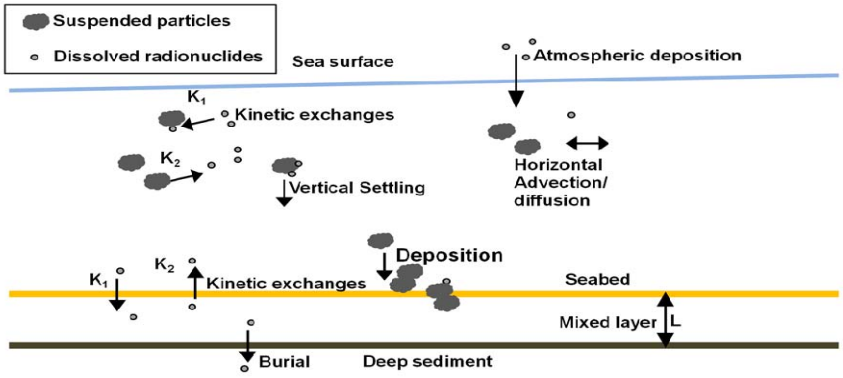

Figure 2. Physical processes for the dispersion of non-conservative pollutants

LORAS consists of terms describing the adsorption/desorption reactions between water, suspended matter and bottom sediments. These processes are formulated using kinetic transfer coefficients and exchanges of radionuclides between water and sediments are governed by a first-order reversible reaction which presented the forward and backward rates respectively. The exchanges between the liquid and solid

phases can be modelled as two decay processes with probability functions. These processes are treated with the same method as the radioactive decay process. This stochastic method in Lagrangian particle model can be extended to the case in which there are three different phase such as water, suspended matter and bottom sediments. Deposition of suspended matter and erosion of sediment are also considered in the particle model. Suspended matter falls to the sea bottom with a settling velocity and erosion of the sediment is described in terms of erosion constant concept. The processes that a particle is removed from the sediment and incorporated to the water as suspended matter can be modelled with probability function like the same method to describe the radioactive decay process.

The particle model in this study was included the terms of decay, adsorption and desorption of the suspended matters, settling down to the seabed and re-suspension of sediments, as well as advection and turbulence(Fig. 2).

The correct information of radionuclides released into the ocean and atmosphere is one of the important key point for dispersion simulations, but the source information is not readily available for this kind of accident. So far, several estimates of the amount of ^{137}Cs discharged into the ocean have been reported. Kawamura et al., (2011) estimated the amount of ^{137}Cs discharged into the ocean using radioactivity data measured near the power plant by TEPCO; they assumed that the observed concentration at the outlet extended over an area of 1.5 km^2 in front of the plant. The source term from TEPCO based on the measured concentration of ^{137}Cs (Fig. 3) has been defined as a ‘‘boundary condition’’ in the grid cell where such point is located in each computational mesh. The results using TEPCO source term showed good agreements with measurements reasonable results in our previous study (Perianez, et al., 2012), thus the same way adopted in this study.

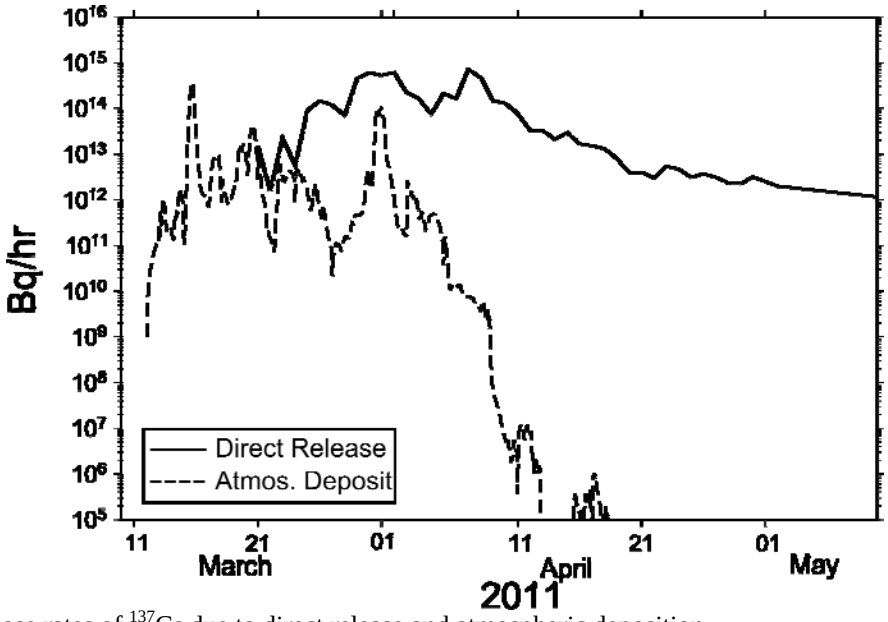

Fig. 3. Release rates of ^{137}Cs due to direct release and atmospheric deposition.

In the early phase of accident from March 15-31, the lots of amounts of ^{137}Cs was deposited on the sea surface due to dry and wet processes, and most of them was deposited in the northeast direction of Fukushima. Especially, large amount of radionuclide was released into atmosphere on March 15 which Unit 2 was damaged at Fukushima NPPs, ^{137}Cs released into the air moved north eastward off Fukushima and light rain was occurred from March 15-17 and large amount of ^{137}Cs deposited in northeast area near a Fukushima sea. Similar patterns occurred from March 31 to April 1. Our simulation results estimated the total deposited amounts of ^{137}Cs was about 5.8 PBq from March 12 to April 6. JAEA estimated that the direct released amount of ^{137}Cs was about 4 PBq from March 21 to April 30 (Kawamura et al., 2011). We can infer from mentioned above that the amount of ^{137}Cs from the atmospheric deposition was larger than it from direct release into the sea. Therefore, it is the important factor to consider the atmospheric deposition for dispersion simulations of radionuclides off Fukushima sea area. The used deposition amount shows in Fig. 3.

RESULTS

Two experiments were performed, one is considered the source term by direct release and the other is including the effect of atmospheric deposition for source term. Measured and calculated concentrations of ^{137}Cs in seabed sediments (left column in Fig. 4) by direct released ^{137}Cs and considering atmospheric deposition and may be seen in right column in Fig. 4, respectively. The calculated seabed concentrations of ^{137}Cs with atmospheric deposition showed better agreements with observations than experiment of only concerned direct release, especially in the northeast parts of Fukushima in Fig. 4. It is that the amounts of ^{137}Cs released in atmosphere was fall out on the sea surface of northeast region of Fukushima due to the dry and wet depositions from 15 to 31 March. The other is that the currents are weak in this region and therefore, ^{137}Cs moved to the seabed due to having the long residence time.

Therefore, the atmospheric depositions of ^{137}Cs must be considered in the early phase of the accident for the more accurate calculation in the seabed sediments. The calculated concentration with atmospheric deposition had good agreements with measurements for the bottom sediments than it without atmospheric deposition.

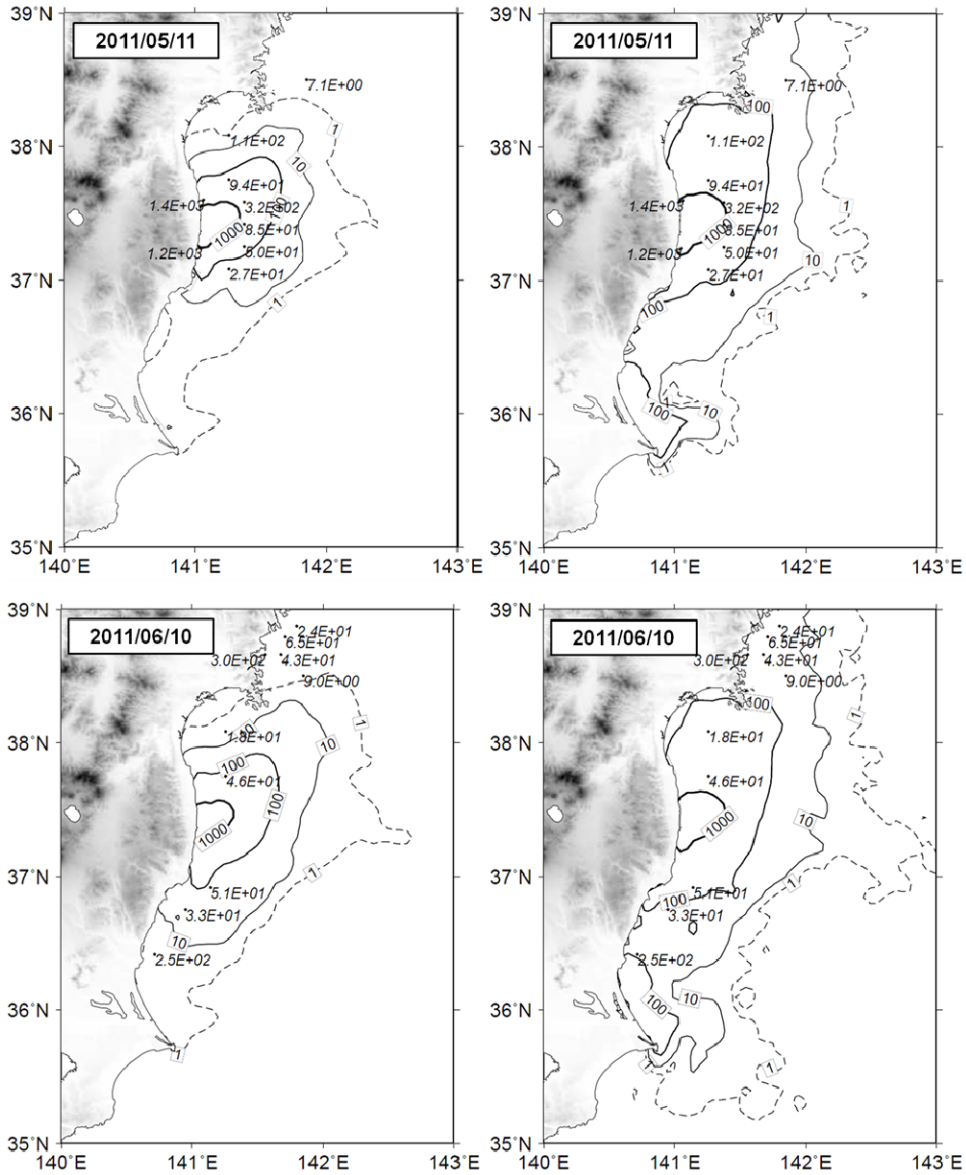

Fig. 4. Concentrations of seabed sediments only direct release (left column) and considering the direct release and atmospherci deposition (right column).

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