2.3 RADIOACTIVE NUCLEI EMISSION ANALYSIS FROM FUKUSHIMA DAIICHI NUCLEAR POWER PLANT BY INVERSE MODEL

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1. Introduction

The accident of the Fukushima Daiichi nuclear power plant that occurred in March 2011 emitted a large amount of radionuclide. The important feature of this accident was that the source position was evidently clear, however, time and vertical emission variations were unknown (in this case, it was known that the height of emission was not so high in altitude). In such a case, the technique of inverse model was a powerful tool to gain answers to questions; high resolution and more precise analysis by using prior emission information with relatively low computational cost are expected to be obtainable.

2. Experimental Method

We used three components in this study: surface observation data, the online global dust aerosol model, and the inverse technique.

We collected atmospheric radionuclide concentrations from various sources. The Comprehensive Nuclear-Test-Ban Treaty (CTBT) foresees a global ban of all nuclear explosions. We also obtain a sub set of European network “Ring of five” observation data (Masson et al., 2011). From this network, we obtain ^{137}Cs observations data. The temporal resolution of these observations is 1 day and we set a large uncertainty for a period when there is no observation data. We assume observation data uncertainty as 20%. The uncertainty contains observation error and representative error. As our aerosol model resolution (TL319; 55km) is so large and it is difficult to simulate observation data where there is not enough distance from the source and we could not ignore contamination (not transport), we set the large uncertainty in Takasaki (about 220km from the source) site. As the number of observation site determines dimension of unknown emission dimension, we set analysis period from 10 Mar to 19 April (40 days). The positions of observation sites are plotted in Figure 1. The time resolution of the observation data is a daily mean.

We used MASINGAR (Tanaka and Chiba, 2005) for forward simulation. MASINGAR can simulate several aerosol species and their precursor gases that include radioactive radon 222 and lead 210. The model is coupled with JMA/MRI general circulation model (GCM; Yukimoto et al., 2012) and uses all GCM parameters (wind, temperature, soil parameters, and so on) without spatial or temporal interpolation. In this study, the horizontal resolution is T319L30 (0.56 degrees in horizontal), and MASINGAR is nudged toward horizontal wind of Japan Meteorological Agency operational global analysis (1.25 degrees in horizontal). In the tagged simulation, radio-active nuclei are assumed to sulfate aerosol. The deposition velocity and wet depositions are similar to that of sulfate aerosol (lognormal size distribution with 0.07um radius).

$$\begin{pmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ y_m \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & \cdot & \cdot & a_{1n} \\ a_{21} & a_{22} & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ a_{m1} & \cdot & \cdot & \cdot & a_{mn} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ x_n \end{pmatrix} \tag{1}$$

$$S(\mathbf{x}) = (\mathbf{y} - \mathbf{A}\mathbf{x})^T \mathbf{C}_y^{-1} (\mathbf{y} - \mathbf{A}\mathbf{x}) + (\mathbf{x}_p - \mathbf{x})^T \mathbf{C}_x^{-1} (\mathbf{x}_p - \mathbf{x}) \tag{2}$$

The radionuclide emission analysis system is based upon the Bayesian synthesis inversion (Tarantola, 1987). This technique assumes that the observations maybe explained by linear combinations of dust fluxes and that the transport itself is a linear operation as well. (Eq. (1)). In this equation, y_i (i=1,…,m) is the daily mean observation data and x_j (j=1,…,n) is the daily mean radionuclide emission flux at the Fukushima grid cell of MASINGAR and A (a_{ij}) is the observational operator obtained from MASINGAR tagged forward simulation from specific time. The a_{ij} comprises an observational operator consisting of a MASINGAR model simulation of a radionuclide flux from the source grid cell and a linear interpolation from the MASINGAR grid-point to the observational site. We analyzed the radionuclide emission flux x to minimize the cost function S(x) in Eq. (2) using singular value decomposition. C_y represents the observation data uncertainty. X_p is prior source information. In our study, we prepare two prior source informations. The first one is Japan Atomic Energy Agency (JAEA) posterior emission analysis (Chino et al., 2011) and the other is Norwegian Institute for Air Research (NILU) prior information (Stohl et al., 2012). The reason we use Stohl’s prior (not posterior) is that their inversed observation network is almost similar to our study and we consider it important to avoid double use

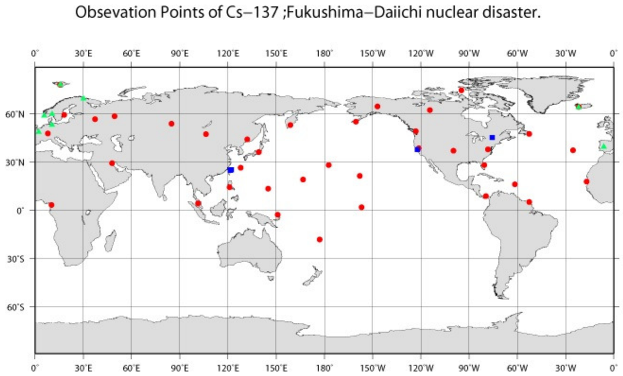

Fig. 1. Observational site map. Red, green and blue circles indicate CTBTO, Ro5 (Masson et al., 2011) and other (Hoffmann (Hoffmann et al., 2000) and Taiwan (Hsu et al., 2012)) sites.

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of observation site. We set C_y to 0.2 considering obserbvation error and spatial representative errors. C_x represents the radionuclide flux uncertainty, which we set from 0.1 (10%) to 20.0 (2000%) in order to obtain suitable prior information and their uncertainty C_x.

3. Results and Discussion

Table 1: Total radionucleide emission amount from 11th March to 19th April (PBq)

Prior Flux uncertainty	0.1	0.2	0.5	1.0	2.0	5.0	10.0	20.0
Chino prior (9PBq)	9.3	13.3	17.4	18.5	18.8	19.5	20.2	20.7
Stohl posterior (28PBq)	18.2	18.7	19.2	19.5	19.9	20.4	21.1	22.0

Table 2: Square of the difference between prior and posterior emission (TBq/h)

Prior Flux uncertainty	0.1	0.2	0.5	1.0	2.0	5.0	10.0	20.0
Chino prior	26.8	56.5	87.0	91.8	87.0	80.4	78.9	78.5
Stohl posterior	93.5	87.5	99.2	102.5	100.8	98.3	97.9	97.8

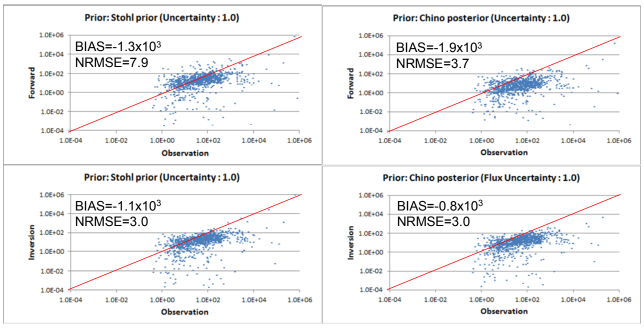

Fig. 2: The scatter plot of model results and observation data. Upper figures show forward simulation results and lower figures show inversed results. The left figures show Stohl prior information results and the right figures show Chino prior information results. BIAS shows a bias between model and observation. NRMSE shows a square root of normalized square mean difference between model and observation.

The table 1 shows a total radionuclide emission amount from 11th March to 19th April. In both prior information, total radionuclide emission amount tend to larger when prior flux uncertainty become large. The table 2 shows a square of the difference between prior and posterior emissions. The value shows a maximum when the prior flux uncertainty is 1.0. This means that observation data are effectively used in this setting. Considering these tables and a difference between total radionuclide emission by Chino (9PBq) and Stohl (29PBq), we select prior flux uncertainty as 1.0.

The figure 2 shows a scatter plot between model results and observation data. In both prior information cases, inversed dose rates tend to closer to observation data. In all cases, MASINGAR could not reproduce high dose rates. Considering a bias between forward simulation results and observation data, we select Chino posterior emission time series as our prior emission time series. Finally we culd obtain total radionuclide emission amount from 11th March and 19th April is 18.5PBq and their uncertainty is 3.6PBq. Maximum emission takes place on 15th March, we analyzed the emission amount is larger than the a priori information. On the other hand, we could not analyze the peak daily emissions of 30th March.

4. Conclusions

We have constructed a system which estimates emissions from the Fukushima nuclear power plant radiation dose using observational data, our transport model and an inverse model. According to the inverse analysis system, the total ^{137}Cs release from the Fukushima Daiichi nuclear power plant is 18.5PBq from 11th March to 19th April. The uncertainty of the estimated total release is about 3.6PBq. Inversed dose rates tend to closer to observations. However, our model could not represent high dose ratio observation data. The limitation of horizontal resolution of the model (about 60km) may be a considerable reason. To obtain more robust results, we need more observation data and higher resolution chemistry transport model.

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