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Detecting Contamination Sources of Radioactive Substance based on Open Data Analysis

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***Abstract*—One of the serious fears for Japanese society is contamination of radioactive substances due to the huge earthquake and subsequent Fukushima No. 1 nuclear power plant disaster. This paper proposes a detection method to identify contamination sources of radioactive substances in the air based on open data, which are composed of air dose rate, amount of rain, wind speed, and direction. To select an appropriate area for analyzing contamination sources with this method, a field investigation is conducted in the west part of Japan, which is in a region approximately one thousand km from the east power plant. Based on the possible contamination origin found in the investigation, open data are analyzed by the method in terms of relationship between air dose rate and weather conditions. Air dose rate is observed on each public monitoring point. The nearest weather observation station for each public monitoring point concerning air dose rate is also identified to analyze the relationship between air dose rate and weather conditions. This method focuses on all cases of continuous rainfall duration, because various sizes of spike concerning air dose rate on a public monitoring point are observed among the cases. Each spike starts when rainfall begins and the spike disappears when rainfall continues. This is because rainfall cleans up radioactive particles in the atmosphere. The method confirms a statistically significant difference of increase rate of air dose rate between each pair among rainfall cases. It also identifies a range of direction from a monitoring point to diffusion sources based on significance tests of correlation coefficients.**

Keywords*— open data, radioactive substance, local society, weather condition, location information

I. Introduction

After the huge earthquake in Japan on March 11, 2011, radioactive substance derived from the Fukushima No. 1 nuclear power plant could affect the world's environment and society. Japanese people were concerned about contaminated food, wood, resources, and goods due to air and water pollution in terms of radioactive substance. According to the nature blog news on December 21, 2012, one of the most interesting articles on social media is an academic article concerning the biological effect of the crippled Fukushima nuclear power plant [1]. Worldwide attention on this article means that the crippled nuclear power plant and diffusion of radioactive substance from the plant are a major concern and threat against our environment.

The Japanese government has a warning system, called SPEEDI (System for Prediction of Environmental Emergency Dose Information) [2], which is supposed to predict the radiation spread based on information concerning power plant, weather conditions, and geographic area in terms of dose rate. SPEEDI is intended to detect a serious accident at a nuclear power plant; however, it is not intended as a secondary diffusion from contaminated goods, water, and other items. In order to specify a radiation level, the Japanese government provides information collected from monitoring points in Japan [3]. This paper analyzes the relationship between radiation level and weather conditions toward development of a detection system to identify sources or origins of spreading radioactive substance.

II. Diffusion of Radioactive Substance

Many researchers have been trying to clarify the environmental and social effects of radioactive substance. Yasunari et al. [4] estimated the amount of radioactive substance on and inside soil in Japan. Koyama drew a contamination map around Shizuoka prefecture due to the Fukushima No. 1 nuclear power plant [5]. Hayashi researched the contamination of wood in forests [6]. The Forestry Agency of Japan provides questions and answers concerning handling wood products because the products might be contaminated [7].

The Ministry of Agriculture of Forestry and Fisheries provides information concerning the limitation of export of Japanese products to other countries, and inspection of agricultural products and fisheries products with respect to cesium 137 contamination [8]. The Ministry of Land, Infrastructure, Transport, and Tourism of Japan provides a report on the result of inspection of drainage and sewage sludge with respect to radiation levels [9]. The Ministry of Health, Labor, and Welfare provides information concerning inspection results of water supply with respect to cesium 137 contamination [10].

According to these reports, agricultural and fisheries products and water supply contain a thousand times contamination of radioactive substance compared to that before the Fukushima nuclear power plant disaster. The clean association of Tokyo 23 waste reports that ashes contain radioactive substance continuously after the disaster. In addition, burning earthquake debris derived from the northeast regions in Japan is another significant concern of spreading radioactive particles because burning earthquake debris could make secondary spreading contamination worldwide, as much as the primary spreading contamination [11] [12].

III. Field Investigation

To find an appropriate source of spreading a radioactive substance, a field investigation was conducted with a recordable Geiger counter and GPS in a car driven among four prefectures in the west part of Japan. The results of this investigation are summarized in Figs. 1, 2, 3, 4, 5, and 6. The x-axis in each figure is the time period, where the unit is a minute. The y-axis in each figure is the air dose rate, where the unit is micro sievert per hour.

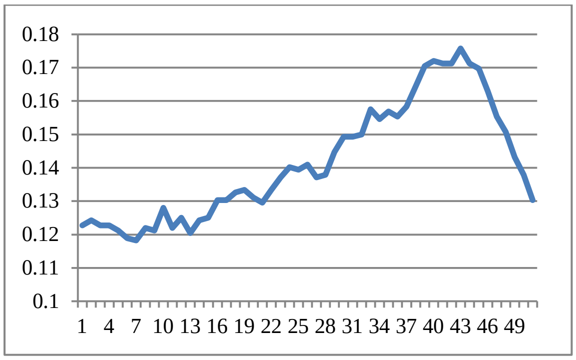

Figure 1. Sanyo Highway from West to East.

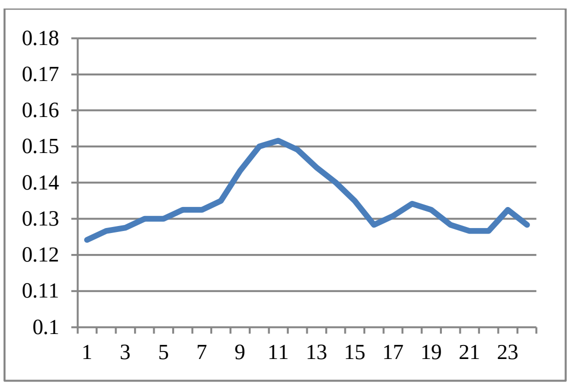

Figure 2. Chugoku Highway from West to East.

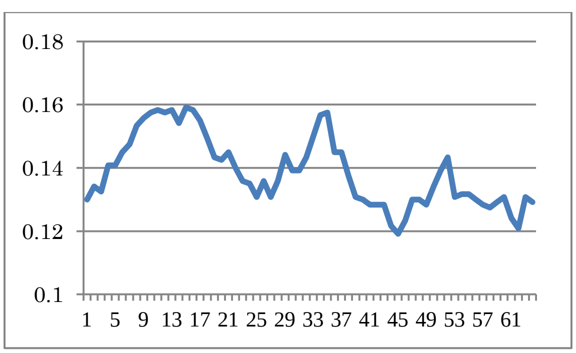

Figure 3. Sanyo, Chugoku and Hamada Highways from South to North.

Between Hatsukaichi and Onomichi cities on Sanyo highway in Hiroshima prefecture, a high air dose rate area is observed around the eastern part of the prefecture (Fig. 1). Between Chiyoda region and Miyoshi city on Chugoku highway in the prefecture, a high air dose area is observed in the middle (Fig. 2). From Sanyo region in the south to Sanin region in the north, through Sanyo, Chugoku, and Hamada highways, three radiation peaks were found. South Mountain tends to get high contamination due to the direct fallout from Fukushima No.1 nuclear power plant [4].

From the north part of Yamaguchi prefecture to the west part of Shimane prefecture (Fig. 4), and the west and east portions of Shimane prefecture (Fig. 5), a higher dose rate of radiation in the western part of each figure was observed compared to the eastern section. However, from the east part of Shimane prefecture to Tottori prefecture, a higher dose area appeared in the eastern section, as shown in Fig. 6.

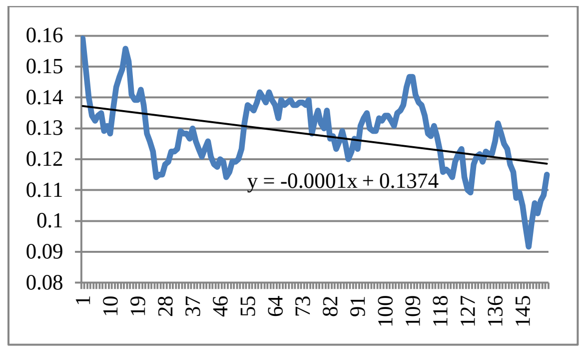

Figure 4. Route 9 between Hagi and Hamada Cities from West to East

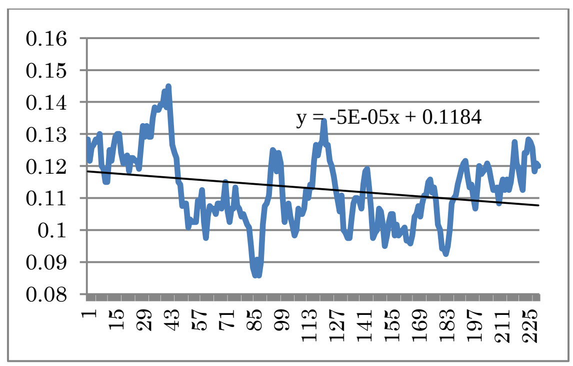

Figure 5. Route 9 between Hamada and Matsue Cities from West to East

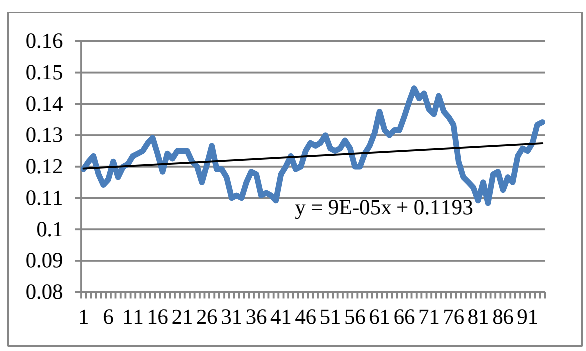

Figure 6. Route 9 between Matsue and Kurayoshi Cities from West to East

West and east parts of Sanin region might face sources of spreading radioactive substance because this region did not get high contamination from the Fukushima fallout. Kaneyasu discussed various types of radioactive cesium, which travelled a long distance with wind blow [13]. The article means that radioactive substance can easily diffuse from a source of contamination.

One of the possible contamination sources is an incineration plant. In the west part of Japan, Kitakyushu city tried to burn earthquake debris from Ishinomaki city in Miyagi prefecture to confirm safety burning on May 23, 2011. After the confirmation, the city has started a two-year burning. In November 2012, Osaka city also tried to burn the same kind of debris from Iwate prefecture.

The Japanese government and the Ministry of Environment allow that the debris can contain radioactive substance under 100 becquerel per kiro gram. According to the FAQ of the Ministry of Environment, filtering an incineration plant can remove 99.9% of the substance, which means that a little substance can diffuse in the air. In this paper, Kitakyushu city was selected as an analysis area because the plants can produce radioactive airborne particles continuously for two years.

IV. Open Data Analysis

Diffusion factors of radioactive airborne particles are analyzed with open data concerning air dose rate, rainfall, wind speed, and wind direction. A set of three incineration plants in Kitakyushu city were employed as safe spreading origins of radioactive airborne particles because the Japanese Ministry of Environment approved the burning earthquake debris contaminated by radioactive substance derived from the Fukushima No. 1 power plant accident.

A monitoring post (MP) of the Yahata common building for government offices in Kitakyushu city was employed for analysis because it was the closest monitoring post from the incineration plants. Employing an original geo-coding database, which has the same function of Google geo-coding API, the nearest weather observation station for each MP is automatically identified in terms of the name of the stations, which contains prefecture and region names. The weather station information is publicly provided by Japan's meteorological agency.

A. *Effective Rainfall Duration, Wind Direction and Wind Speed*

This paper proposes a method to identify diffusion sources of sparse radioactive small particles based on air dose rate, amount of rainfall, wind direction, and speed. It is difficult to measure radioactive small particles with monitoring points managed by the Ministry of Education and Culture, Sports, Science and Technology of Japan, because they are intended to measure high dose rate due to the serious effect of the severe nuclear power plant accident. However, they are able to detect the small particles when rainfall starts because it brings the particles to the ground from the air. Hence, based on the amount of increase, this method identifies diffusion sources with wind direction and speed.

Radioactive small particles contribute increase of air dose rate when rain falls. Hence, this method determines all durations of effective rainfall in terms of continuous rainfall. In the early stage of rainfall, radioactive small particles in the atmosphere have begun to drop on the ground, and they contribute an increase of air dose rates of monitoring points. When rainfall has continued long term, the dose rates are going to return to the normal rates because there are no more small particles in the air. Hence, the effective rainfall duration is defined as duration between the beginning of rainfall and the time period of returning to the normal air dose rate.

Eight cases of effective rainfall duration are extracted from one month dataset concerning a monitoring post of Yahata common building for government offices in Kitakyushu city and Yahata weather station. Figure 7 illustrates air dose rate, rainfall, and coefficient of wind direction and speed. In order to illustrate the values in a figure, air dose rate and rainfall are rescaled between 0 and 1 based on the minimum and maximum values, respectively. The minimum and maximum values of air dose rate are 0.0578 and 0.091333, respectively. The values of rainfall are 0 and 41, respectively. Coefficient of wind direction and speed (w) is defined as the following formula:

$$w = \frac{1}{2}\left(1 - \frac{1}{1+s}\right)\left(1 + \cos\left(\frac{\pi(\theta-\alpha)}{180}\right)\right) \quad (1)$$

where s is wind speed, θ is wind direction at a monitoring point, and α is direction to a diffusion source from the monitoring point.

North, east, south, and west winds are 0, 90, 180, and 270 on wind direction (θ), respectively. On one hand, when wind is from a diffusion source (θ=α), w approaches to 1 from 0.5. On the other hand, when wind flow is the opposite direction (θ=α+180), w approaches to 0 from 0.5. When wind speed (s) is slow, w approaches to 0.5.

According to Fig. 7, when heavy rainfall is observed, high air dose rate per hour is observed, e.g., (c5) in Fig. 7. On the other hand, when light rainfall is observed, low air dose rate per hour is observed, e.g., (c6) in Fig. 7. In order to measure the amount of radioactive small particles in the air without the effect of different amounts of rainfall, the method evaluates increase of air dose rate per rainfall of one millimeter per hour. Hence, the method can compare the amount of radioactive small particles among different cases of effective rainfall duration.

Figure 8 shows increase of air does rate per unit of rainfall. Table 1 and Fig. 9 show effective rainfall duration, average, and standard deviation of increase of air dose rate. The increase of air dose rate is defined by the difference between a value of each time period and the minimum value among all eight cases. The cases are numbered in descendant order in terms of average of increase of air dose rate.

In order to discuss statistically significant differences of average of increase of air dose rate, three groups (group A of case 1 and 2, group B of case 3, 4, and 5, and group C of case

6, 7, and 8) are separated based on a statistical test of population variance with significance level of 5%. In each group, there is no significant difference on each pair of two cases based on a statistical test of difference of population mean with significance level of 5%. However, concerning three pair of cases among the different groups, there are significant differences between case 3 and three cases (case 6, 7, and 8), in terms of Welch's t-test with a significance level of 5%.

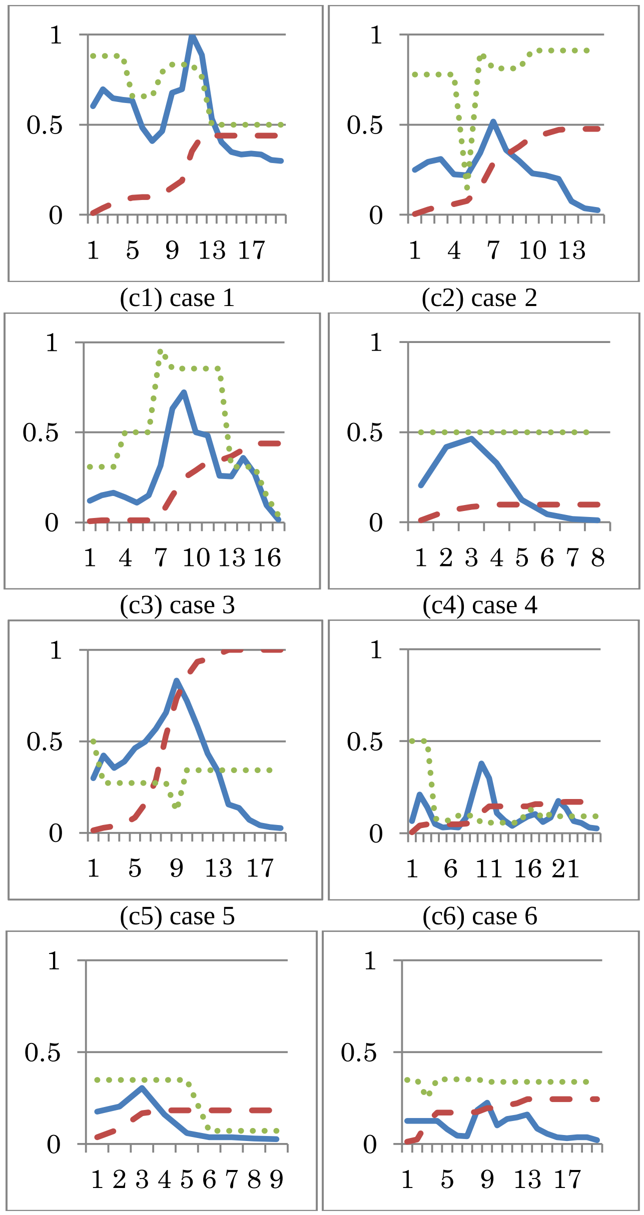

Figure 7. Air dose rate, rainfall, wind direction, and speed

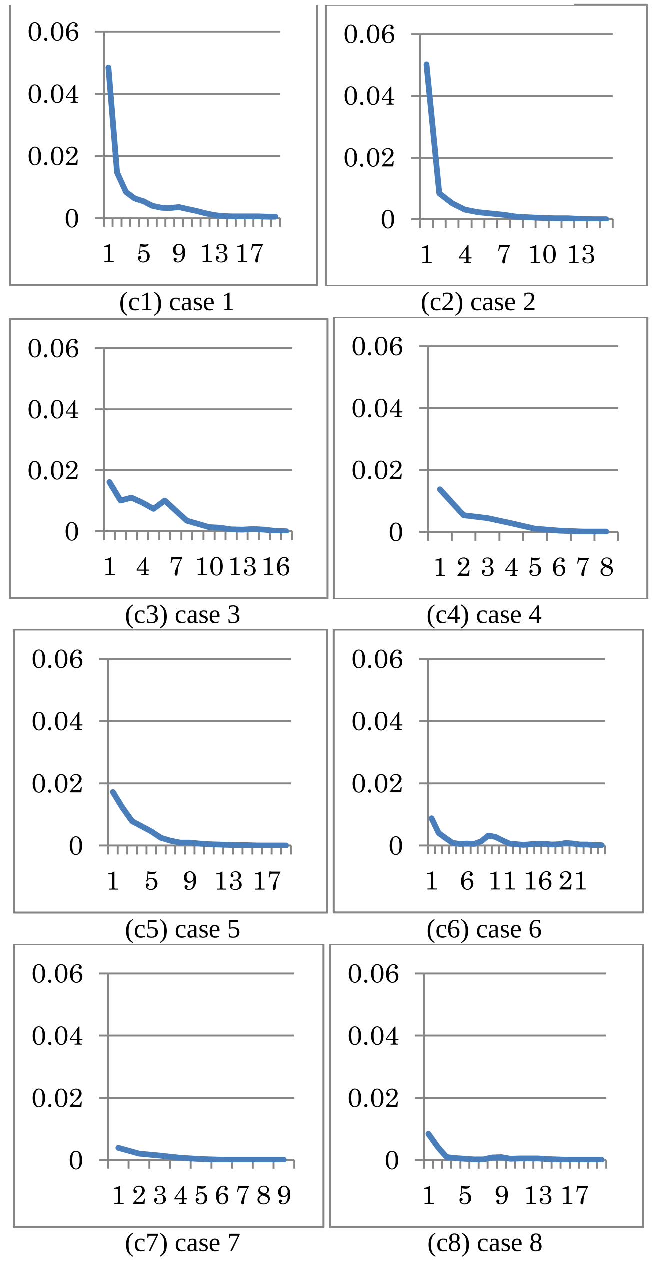

Figure 8. Increase of air dose rate per rainfall

TABLE I. EFFECTIVE RAINFALL DURATION, AVERAGE, AND STANDARD DEVIATION OF INCREASE OF AIR DOSE RATE

	Hour	Average	SD
Case 1	20	0.00551	0.01070
Case 2	15	0.00504	0.01271
Case 3	17	0.00482	0.00501
Case 4	8	0.00350	0.00460
Case 5	19	0.00297	0.00478
Case 6	25	0.00129	0.00187
Case 7	9	0.00100	0.00129
Case 8	20	0.00099	0.00196

B. *Identifying Range of Existence of Contamination Sources*

In order to identify the existence range of diffusion source, correlation between unit increases of air does rate and coefficient of wind direction and speed is calculated for α from 0 to 359 with step one degree. Figure 9 illustrates the correlation and α, which is direction to a diffusion source from the monitoring point. According to a statistical test of popular correlation, the range between 76 and 113 is a significant range, where correlation is equal or greater than 0.8340, where F is greater than 13.7450, and it is the boundary of critical region of significance level of 1%. For significance level of 5%, the range between 64 and 137 is significant range, where correlation is equal or greater than 0.7068, where F is greater than 5.9874. The maximum direction is 92 degrees, where the maximum correlation is 0.8881. All coefficients of wind direction and speed are depicted in Fig. 9. The scatter diagram is illustrated in terms of coefficient of wind direction and speed and increase of air dose rate in Fig. 10.

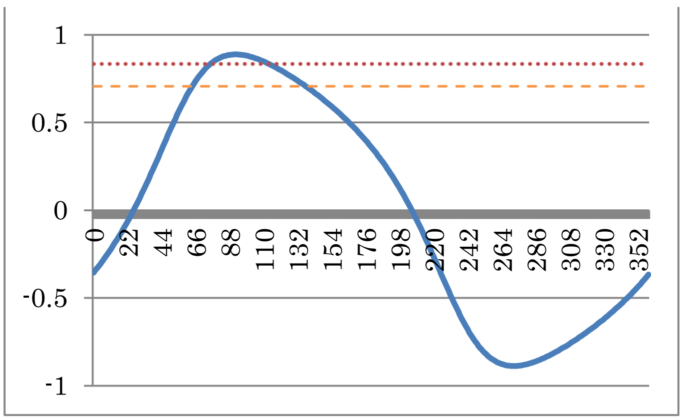

Figure 9. Direction of diffusion source and correlation

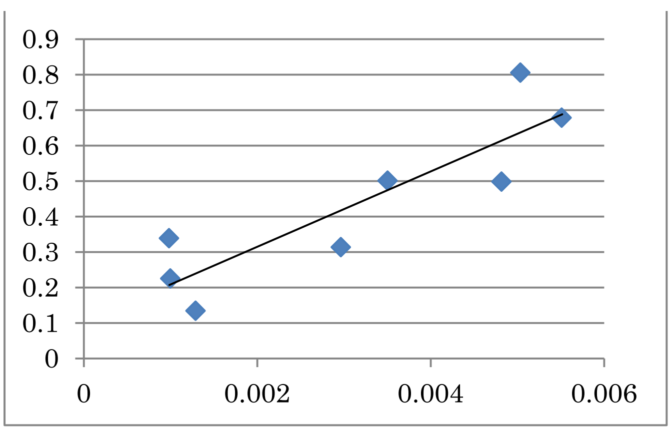

Figure 10. Coefficient of wind direction and speed and increase of air dose rate

Figure 11 shows the monitoring point (MP) and three incineration plants with existence range of diffusion sources. Table II shows geographical location, distance, and direction concerning MP and three incineration plants. The third incineration plant in Shinmoji in Table II is located in the strict existence range between 76 and 113. The direction of the plant from MP is 90.0865, which is very close to the maximum degree 92. The second plant in Hiagari in Table II is located in the existence range between 64 and 137. The first plant in Kougasaki in Table II is outside of the range; however, the distance to MP is very close. Hence if the first plant in Kougasaki diffuses radioactive small particles, they have a continuous effect to MP in any wind direction. The range on the south part of the region is bigger than the north part in Fig 11. The south part is composed of downtown and forest, while the north part is coastline. The downtown and forest keep radioactive small particles from diffusion sources. Hence, the reason of the wide range in the south part is that the southeast wind brings the particles from the south part to MP.

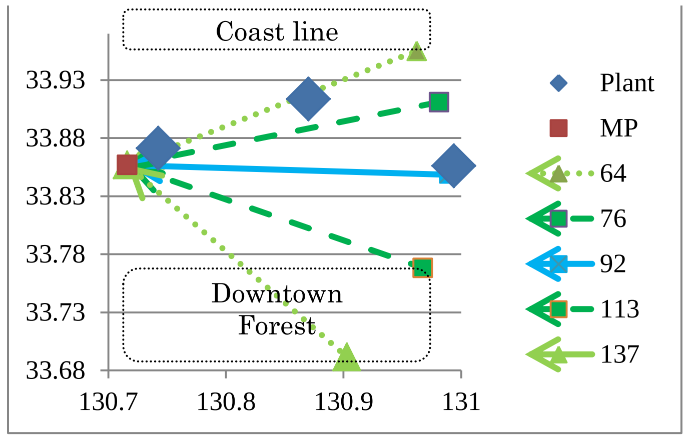

Figure 11. Existence Range of Diffusion Source

TABLE II. MONITORING POINT AND THREE INCENERATION PLANTS

Name	Latitude	Longitude	Distance to MP	Direction from MP
Yahata common building for government offices in Kitakyushu city (MP)	33.8567	130.7163	0.0000	
Kougasaki	33.8711	130.7427	1.5741	56.8248
Hiagari	33.9135	130.8703	8.3925	66.0353
Shinmoji	33.8561	130.9939	13.8311	90.0865

V. Conclusion

This paper proposed a statistical method to find diffusion sources of radioactive substances. Diffusion of radioactive substance could be a major concern worldwide. In section II, this paper summarized the contamination derived from the Fukushima No. 1 nuclear power plant in Japan. To find an appropriate analysis area of spreading radioactive substance, a field investigation was conducted with a survey meter on an automobile. Around the possible found area in field investigation, data concerning air dose rate and weather conditions were analyzed on the nearest MP of the spreading area. The detection method identifies contamination sources of radioactive substances in the air based on open data, which are composed of air dose rate, amount of rain, wind speed, and direction. This method focuses on all cases of continuous rainfall duration because of the various sizes of spike concerning air dose rate on a public monitoring point. Each spike starts when rainfall begins while the spike disappears when rainfall continues because rainfall cleans up radioactive particles in the atmosphere. The method confirms a statistically significant difference of increased rate of air dose rate between each pair among rainfall cases. It also identifies a range of direction from a monitoring point to diffusion sources based on significance tests of correlation coefficients.

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