Forest air dose rates: Comparisons of the measurement values between old and new survey meters

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Abstract

This study investigated whether differences existed in the measured values between the old and new NaI (Tl) scintillator survey meters (hereafter: survey meter) used to measure the air dose rates in the forests of Fukushima Prefecture. The research was conducted at three sites in Kawauchi village, Fukushima Prefecture (a Japanese cypress forest and a deciduous broad-leaved forest at the Mitsuishi site and a Japanese cedar forest at the Kanayama site), and the air dose rates were measured at heights of 1 m and 10 cm above the ground surface at 50 different points using four survey meters (two new and two old models). The comparisons revealed no significant differences in the air dose rates at heights of 1 m and 10 cm between the same survey meters (for both the old and new models). The results also confirmed that there were no differences in the measured values of the air dose rates between the new and old models. These results indicated that 1) even when two survey meters are simultaneously used to efficiently measure the air dose rates in the forest, the measured values of the air dose rates are unaffected, and 2) updating the survey meter from an old to a new model does not affect the assessment of the interannual variability in the air dose rates.

1. Introduction

In March 2011, the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident released radiocesium into the atmosphere, and the radiocesium contaminated the forests in Fukushima Prefecture. Since 2011, the Forestry and Forest Products Research Institute (FFPRI) has conducted monitoring surveys every year to determine the distribution of radiocesium in these forests (Komatsu et al., 2016; Imamura et al., 2017). In addition, this research group has continued to measure the air dose rate (μSv/h) in the forests at heights of 1 m and 10 cm above the ground surface (Forest Agency, 2021). At each location, the air dose rates were measured at 10-m interval grid points. The output value of an NaI (Tl) scintillator survey meter (hereafter, survey meter) was recorded 90 s after the start of the measurement. Since the survey would take too long to complete using only one survey meter, the air dose rate was measured using two survey meters of the same model. However, even though the survey meters used were calibrated and of the same model, it cannot be sufficiently verified whether the measured values in the forests vary between meters.

As more than 10 years have passed since the FDNPP accident, disconnection issues have recently emerged at the cable connections of the survey meters (TCS-172B, Hitachi-Aloka Medical, LTD., Japan). In addition, the calibration factor of the survey meters significantly varies depending on the measurement range (e.g., a calibration factor of 0.5 μSv/h has a calibration point of 0.98, and a calibration factor of 5 μSv/h has a calibration point of 1.04). Therefore, our research group updated to a new model of survey meter (TCS-1172, Hitachi, LTD., Japan) for the 2021 measurements. Accordingly, it is necessary to determine whether this change in instrument affected the measurements of the interannual variations in the air dose rate.

In this study, the air dose rates were measured at heights of 1 m and 10 cm above the ground surface at a total of 50 points using four survey meters (two old models [TCS-172B] and two new models [TCS-1172]). By comparing each measured value, it was determined whether differences existed in the measured values of the air dose rates between the old and new models in the forests of Fukushima Prefecture.

2. Methods

This study was conducted at three sites in the village of Kawauchi in Fukushima Prefecture (a Japanese cypress forest and a deciduous broad-leaved forest at the Mitsuishi site and a Japanese cedar forest at the Kanayama site [see Fig. 1]). A summary of these sites and the measurement dates are presented in Table 1.

For the air dose rate measurements, two old model survey meters (TCS-172B, Hitachi-Aloka Medical, LTD., Japan) and two new model survey meters (TCS-1172, Hitachi, LTD., Japan) (Fig. 2) were used. Here the relative errors of the measured values were both ±15%. In this report, the two old models are referred to as "O1" and "O2" and the two new models as "N1" and "N2". The air dose rates were measured at heights of 1 m and 10 cm above the ground surface at 10-m interval grid points (50 points in total) in each study plot. The time constant of all survey meters was set to 10 s, and the output values of the survey meters were recorded 90 s after the start of the measurement (as performed by Imamura et al. [2018]). The measured values were corrected by multiplying the calibration factor of each survey meter.

This study utilized the MATLAB software for the comparison of the air dose rates. A robust linear regression (MathWorks, 2021) was employed to evaluate whether the measured air dose rates corresponded one-to-one between the instruments. Here, the robust linear regression is a model in which the influence of any outliers is reduced compared with the normal linear regression model (the least-squares approximation). The 99% confidence intervals of the regression coefficients and intercepts were calculated, and it was determined whether they were significantly different from one and zero, respectively (i.e., whether the measured air dose rates corresponded one-to-one).

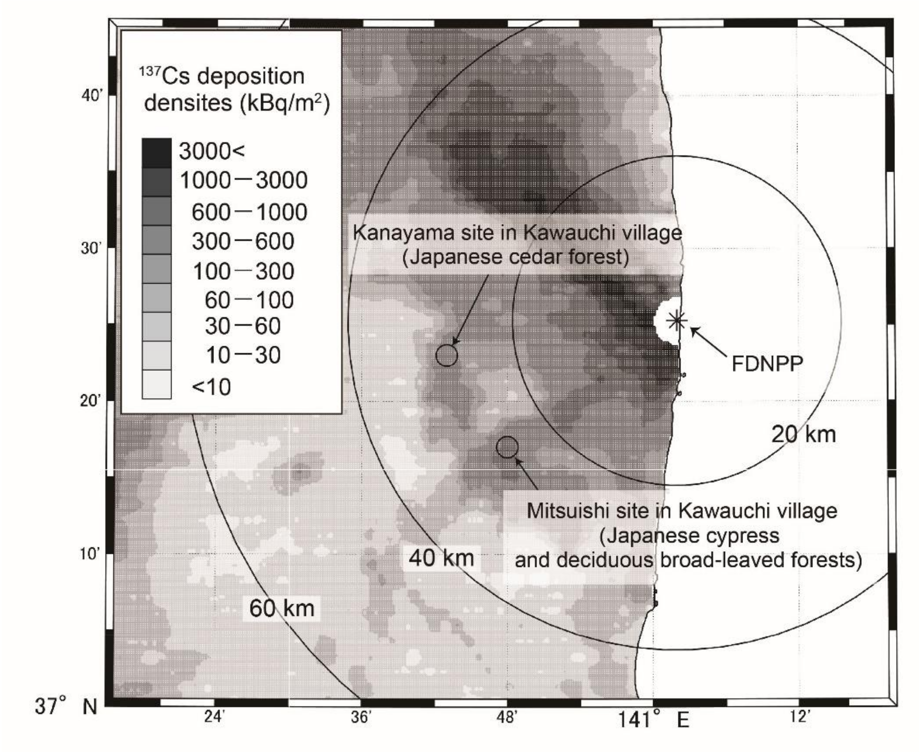

Fig. 1. The locations of the study sites in Kawauchi village in Fukushima Prefecture and the ^{137}Cs deposition densities. The ^{137}Cs deposition densities were obtained from the sixth airborne monitoring (decay-corrected to December 28, 2012) (MEXT, 2013), and the map was obtained using MATLAB and the M_Map mapping package (Pawlowicz, 2019).

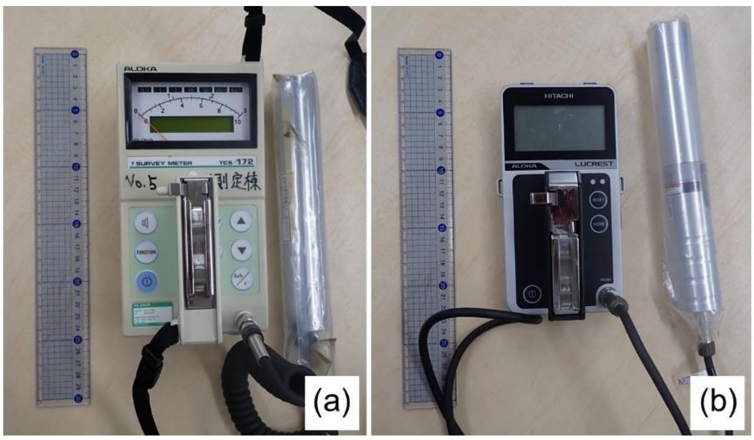

Fig. 2. (a) Image of the survey meter (TCS-172B) used by the FFPRI and (b) image of the new survey meter (TCS-1172).

Table 1. Summary of the study plots in Kawauchi village and the measurement dates of the air dose rates.

Site name	Kawauchi village		
	Mitsuishi		Kanayama
Forest type	Japanese cypress plantation	Secondary deciduous broad-leaved forest	Japanese cedar plantation
Latitude	37°17′22″	37°17′22″	37°22′53″
Longitude	140°47′33″	140°47′30″	140°42′58″
Altitude (m)	720	720	690
Plot area (ha)	0.1	0.06	0.12
Number of observation points for air dose rate	18	12	20
^{137}Cs deposition (kBq/m^2)	470	470	160
Dominant species	*Chamaecyparis obtusa*	*Quercus serrata*	*Cryptomeria japonica*
Stand age (years old)	36	36	65
Measurement date	8/19/2021	8/20/2021	8/18/2021

The values for the summary of study plots are cited from Imamura et al. (2017). The stand age is the value in 2021.

3. Results and Discussion

3.1. Comparison of air dose rates between the same survey meter models

The measured air dose rates between the same survey meter models (Fig. 3) were compared. As a result of the comparison of the measured values at the same grid points (50 points in total) at a height of 1 m above the ground surface (Figs. 3a and b), the 99% confidence intervals of the robust regression coefficients overlapped with one (Table 2). In addition, the 99% confidence intervals of the intercepts overlapped with zero (Table 2). These results indicated that there was no significant difference in the measured air dose rate at a height of 1 m between the same models. In the measured air dose rates at a height of 10 cm (Figs. 3c and d), the 99% confidence intervals of the regression coefficients (intercepts) overlapped with one (zero) (Table 2), confirming that there was no significant difference between the same models in the measurements obtained at a height of 10 cm.

The air dose rates at a height of 10 cm had a relatively large root-mean-square error (RMSE) of the regression line compared with the rates at a height of 1 m. In this report, the time constant of all survey meters was set to 10 s, and the output values of the survey meters were recorded 90 s after the start of the measurement. However, the air dose rates at a height of 10 cm significantly fluctuated after waiting for 90 s, especially in the cypress and deciduous broad-leaved forests at the Mitsuishi site. This short-term fluctuation in the air dose rates may have caused the relatively large RMSE in the analysis at the 10-cm height. Further observation and verification are required to determine the amplitude of the air dose rates on a timescale of several seconds to several tens of seconds.

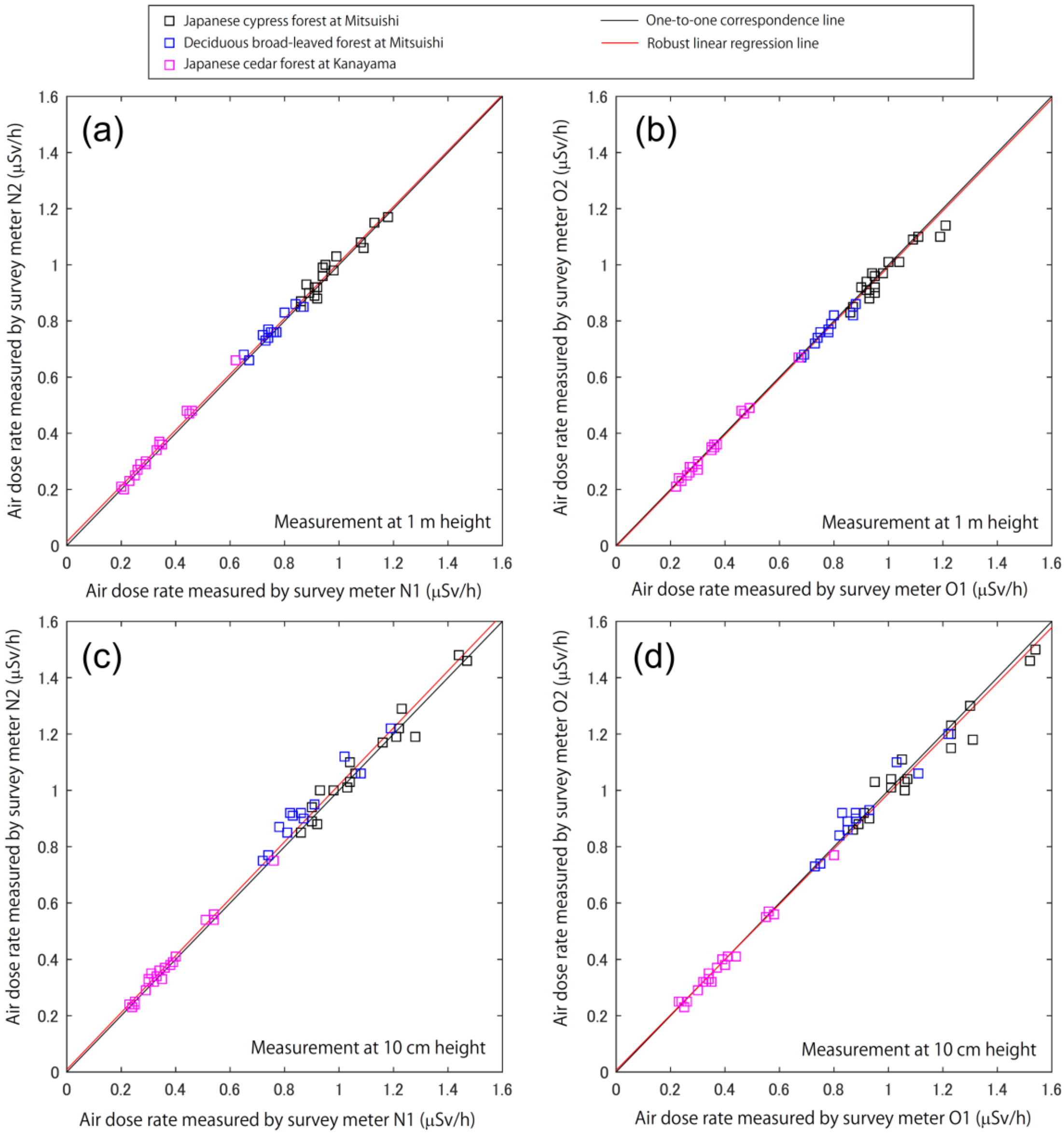

Fig. 3. Comparisons of the air dose rates between the same measurement instruments at the Mitsuishi and Kanayama sites in Kawauchi village, Fukushima Prefecture (cypress site at Mitsuishi: black square; deciduous broad-leaved site at Mitsuishi: blue square; cedar site at Kanayama: magenta square). The air dose rates were measured using (a) new survey meters (TCS-1172: N1 and N2) and (b) old survey meters (TCS-172B: O1 and O2) at a height of 1 m above ground. (c) and (d) are similar to (a) and (b), except for the 10-cm above-ground measurement. The solid black line is the one-to-one correspondence, and the solid red line is the robust linear regression (MathWorks, 2021).

Table 2. The coefficients of robust regression lines, 99% confidence intervals in air dose rate comparisons, and RMSEs of the measurement instruments.

	Measurement height	Regression coefficient	99% Confidence interval of the regression coefficient	Intercept	99% Confidence interval of intercept	Root-mean-square error (RMSE)
New survey meter	1 m	0.995	0.969 ～ 1.02	0.0137	−0.0053 ～ 0.0326	0.0206
Old survey meter	1 m	0.996	0.974 ～ 1.02	-0.00346	−0.0201 ～ 0.0132	0.018
New survey meter	10 cm	1.01	0.975 ～ 1.05	0.00875	−0.0217 ～ 0.0392	0.0343
Old survey meter	10 cm	0.983	0.950 ～ 1.01	0.00635	−0.0213 ～ 0.0339	0.0309

3.2. Comparison of the air dose rates between the new and old survey meter models

The measured air dose rates of the new and old survey meters were compared. As a result of the comparison of the air dose rates at the same points (a total of 50 points) at a height of 1 m above the ground surface (Fig. 4), all regression coefficients (intercepts) of the robust linear regression lines overlapped with one (zero) (Table 3). This result indicated that there was no significant difference in the measured values of the air dose rates between the new and old survey meters. Similar comparisons at a height of 10 cm revealed that there was no significant difference in the measured values between the new and old measurement instruments (Fig. 5, Table 3). However, it was confirmed that the RMSE at the 10-cm height was relatively larger than the RMSE at the 1-m height (Fig. 5b, Fig. 5c, and Table 3). Therefore, the measurement validation at the 1-m height is likely to be more accurate than that at the 10-cm height due to the smaller fluctuation amplitude during the measurement at the 1-m height.

In this study, the presence or absence of differences in the air dose rate measurements between the instruments was evaluated using data from the Mitsuishi and Kanayama sites in Kawauchi village, Fukushima Prefecture. In Kawauchi, the spatial distribution of the air dose rates in the study plot was reported to have a large heterogeneity due to the forest edge effect (Imamura et al., 2018). Conversely, there were study sites where the heterogeneity of the air dose rates in the study plot was relatively small (e.g., the Japanese cedar site in Otama village, Fukushima Prefecture) (Imamura et al., 2020). It is difficult to use the linear regression model evaluation method employed in this report at survey sites where the spatial distribution of the air dose rate has few heterogeneities because the air dose rate data are intensively plotted in a specific range. Therefore, it should be noted that the evaluation method in this report cannot be applied to all cases.

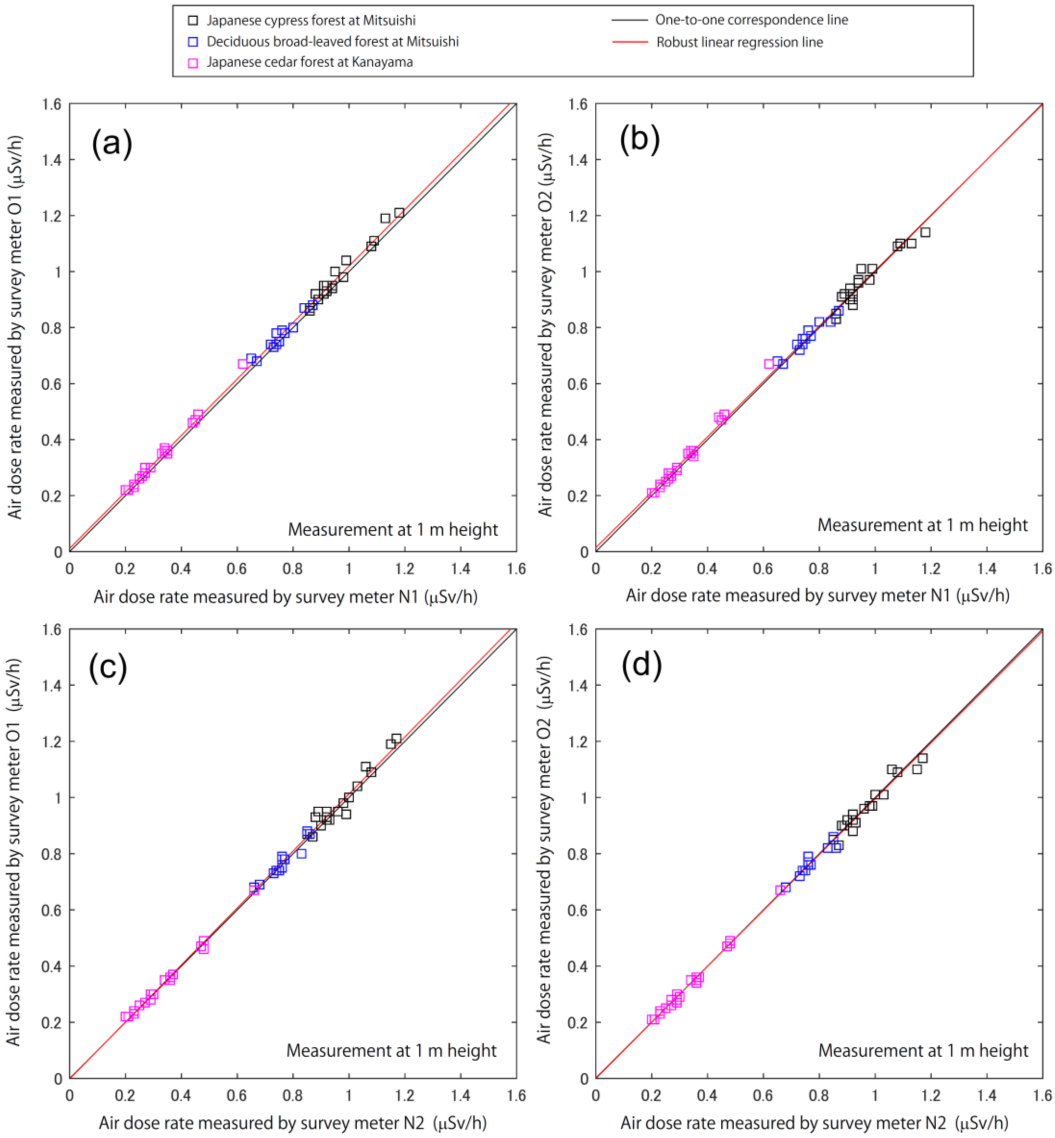

Fig. 4. Comparisons of the air dose rates (at an above-ground height of 1 m) between the new and old measurement instruments at the Mitsuishi and Kanayama sites (cypress site at Mitsuishi: black square; deciduous broad-leaved site at Mitsuishi: blue square; cedar site at Kanayama: magenta square) in Kawauchi village, Fukushima Prefecture: (a) new survey meter N1 vs. old survey meter O1, (b) new survey meter N1 vs. old survey meter O2, (c) new survey meter N2 vs. old survey meter O1, and (d) new survey meter N2 vs. old survey meter O2. The solid black line is the one-to-one correspondence, and the solid red line is the robust linear regression line (MathWorks, 2021).

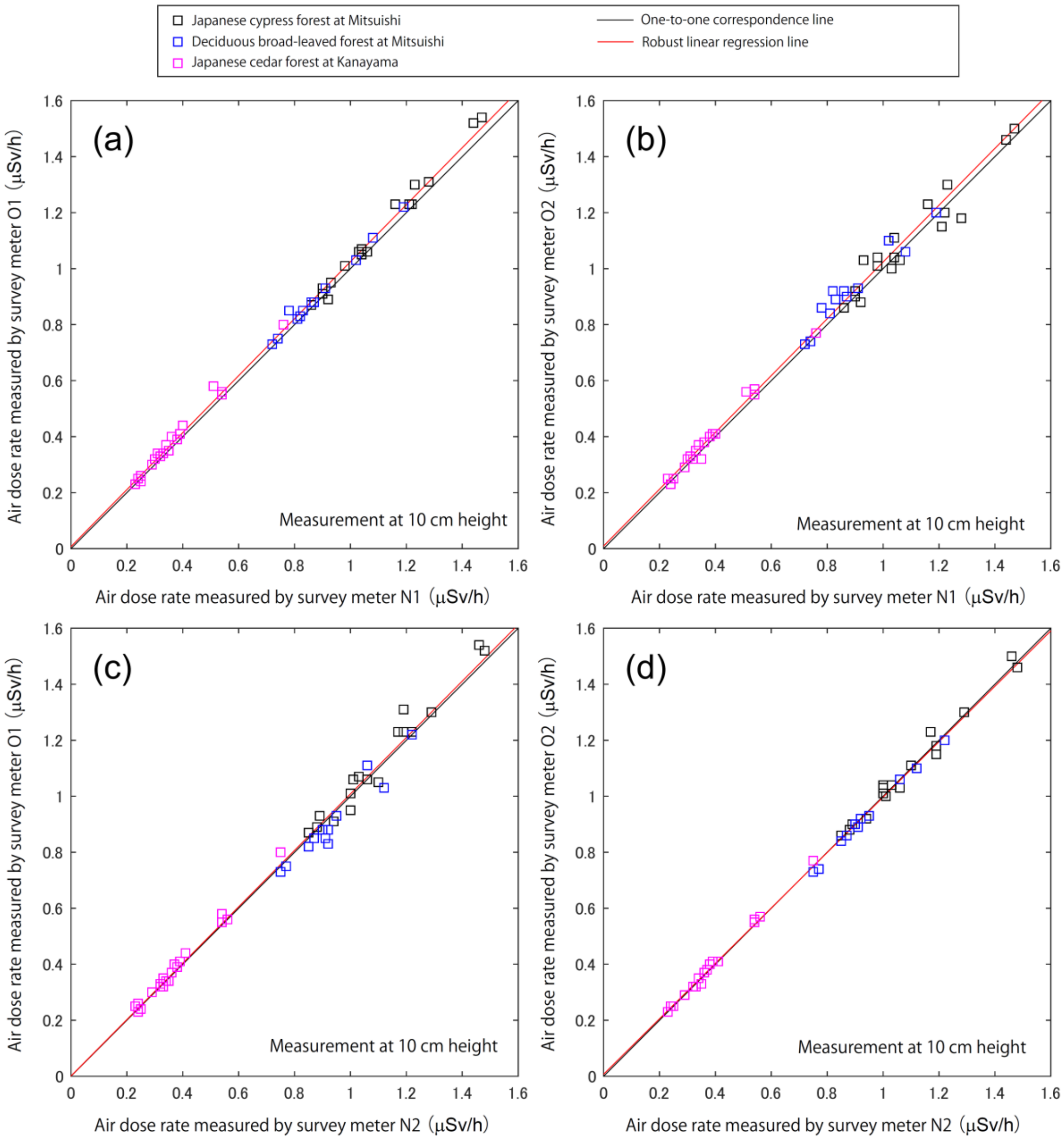

Fig. 5. Comparisons of the air dose rates (at an above-ground height of 10 cm) between the new and old measurement instruments at the Mitsuishi and Kanayama sites (cypress site at Mitsuishi: black square; deciduous broad-leaved site at Mitsuishi: blue square; cedar site at Kanayama: magenta square) in Kawauchi village, Fukushima Prefecture: (a) new survey meter N1 vs. old survey meter O1, (b) new survey meter N1 vs. old survey meter O2, (c) new survey meter N2 vs. old survey meter O1, and (d) new survey meter N2 vs. old survey meter O2. The solid black line is the one-to-one correspondence and the solid red line is the robust linear regression line (MathWorks, 2021).

Table 3. Coefficients of robust regression lines, 99% confidence intervals in the air dose rate comparisons between the new and old measurement instruments, and RMSEs.

	Measurement height	Regression coefficient	99% Confidence interval of the regression coefficient	Intercept	99% Confidence interval of intercept	Root-mean-squared error (RMSE)
N1 vs. O1	1 m	1.01	0.987 ～ 1.03	0.0116	−0.0035 ～ 0.0267	0.0165
N1 vs. O2	1 m	0.99	0.962 ～ 1.02	0.0145	−0.0054 ～ 0.0344	0.0217
N2 vs. O1	1 m	1.01	0.992 ～ 1.04	-0.00182	−0.0184 ～ 0.0147	0.0178
N2 vs. O2	1 m	0.994	0.971 ～ 1.02	0.00193	−0.0146 ～ 0.0185	0.0178
N1 vs. O1	10 cm	1.02	0.998 ～ 1.04	0.00701	−0.0089 ～ 0.0231	0.0181
N1 vs. O2	10 cm	1.01	0.975 ～ 1.05	0.00927	−0.0237 ～ 0.0423	0.0372
N2 vs. O1	10 cm	1.01	0.969 ～ 1.05	0.0008	−0.0323 ～ 0.0339	0.0369
N2 vs. O2	10 cm	0.99	0.971 ～ 1.01	0.00724	−0.0089 ～ 0.0234	0.018

4. Summary

In this report, the air dose rates at heights of 1 m and 10 cm above the ground were compared using two newly introduced survey meters (new model: TCS-1172) and two conventional survey meters (old model: TCS-172B). The results indicated that there were no significant differences in the measured values between the same models or between the old and new survey meters. These comparisons reveal (1) that the differences are minimal when two people use the same model of survey meter and measure the air dose rate at the same time and that 2) updating the survey meter from the old to the new model has few effects on the evaluation of the interannual variation in the air dose rates.

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