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Analysis of Air Purification in a Woodland by Field Observation and Wind Tunnel Experiment

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Abstract – As part of a comprehensive study of the harmonious coexistence between man and nature focusing on woodland, we evaluated the role of the Ryukoku forest in air purification. The Ryukoku forest, located at Seta Hill in Shiga Prefecture, Japan, is composed of a mixture of conifer and deciduous trees. There are two mechanisms in purifying forest air: the deposition of air pollutants onto leaf surfaces and the effect of a tree wind break (air pollutant break). We measured the vertical distributions of nitrogen dioxide (NO_2) concentration inside and outside the Ryukoku forest using passive samplers attached to a 25-m-tall observation tower and to the neighbouring university campus buildings, respectively. Wind tunnel experiments that treat atmospheric dispersion in model trees but cannot consider the effect of deposition have been conducted to evaluate the effect of a tree wind break. The observed NO_2 concentrations in the Ryukoku forest showed a 5 - 20 percent decrease depending on the season towards the forest floor from the top of the canopy. Within the forest canopy layer, the average NO_2 concentration was approximately 30 percent lower than that outside the forest. The results of the wind tunnel experiment showed a similar decrease in the concentration of air pollutants inside the forest. However, the decrease in the concentration of air pollutants towards the forest floor from the top of the canopy was not observed in the wind tunnel experiment. It is deduced that the low NO_2 concentration inside the forest compared with that outside is mainly due to tree wind break effect and that the variation in NO_2 concentration with height from the forest floor is mainly due to the deposition of air pollutants onto leaf surfaces.

Keywords**:** Atmospheric Environment, Air Purification, Nitrogen Dioxide, Forest Canopy, Woodland, Wind Tunnel Experiment, Atmospheric Dispersion, Deposition.

1. Introduction

It is well known that a forest contributes to the effective improvement of the atmospheric environment because it plays a crucial role in air purification by the uptake and deposition of air pollutants. Field observation studies of forest air pollutants are found in the literature (for example, Krzyzanowski, 2004; Fontan et al., 1992). It is however important to accumulate observation data at various forest sites considering vegetation and meteorological conditions. In this study, as part of a comprehensive study of the harmonious coexistence between man and nature focusing on woodland, we

measured the distributions of nitrogen dioxide (NO_2) concentration inside and outside the Ryukoku forest located at Seta Hill in Shiga Prefecture, Japan.

There are two mechanisms in purifying forest air: the deposition of air pollutants onto leaf surfaces and the effect of a tree wind break (air pollutant break). A wind tunnel experiment to determine the effect of the canopy layer on flow turbulence has been conducted by Pretri et al. (2009), but no study of the effects of air pollutant break has been found. We therefore conducted wind tunnel experiments to elucidate the change in air pollutant concentration from the viewpoint of atmospheric transport and dispersion.

2. Field Observation

Seta Hill, Shiga Prefecture, Japan, is near the Kansai metropolitan area, which includes Osaka and Kyoto. Seta Hill includes the Ryukoku forest, a 38-ha woodland area primarily composed of konara oak (deciduous trees), longstalk holly (broad-leaved evergreen), Japanese red pine and hinoki cypress (coniferous trees). The study area is the Ryukoku forest and the neighbouring Ryukoku University campus located 150-160 m a.s.l. at N35.0 deg., E135.9 deg., approximately 15 km east of central urban Kyoto. A 25-m-tall observation tower was set up in the forest. The tower has a fetch longer than 350 m. The height of the canopy top varied from 15 to 20 m, forming a canopy layer of 10 to 15 m thickness depending on the season. The leaf area index (LAI) of the canopy at the observation tower was 4.2 in autumn.

Each measurement was performed for 3 days, once or twice a month from January to December 2013. NO_2 was collected using an Ogawa passive sampler (Web-1), and NO_2 concentration was determined using a spectrometer (Shimadzu UV2550). Twelve passive samplers were attached to the observation tower at heights between 0.1 and 25.1 m. The vertical distribution of NO_2 concentration was also measured at heights between 1.5 m and 30 m using passive samplers attached to university campus buildings outside the Ryukoku forest. Wind speed and wind direction were measured at heights of 5 and 25 m using the observation tower in the Ryukoku forest and at a height of 6 m using a mast in the university campus.

3. Wind Tunnel Experiments

Wind tunnel experiments were conducted using facilities at the Meteorological Research Institute. The test section of the wind tunnel was 18 m long, 3 m wide and 2 m high. A grid and rods were placed at the entrance to the test section and 10 mm cubes were placed at the floor of the test section to produce a suburban atmospheric boundary layer. Figure 1 shows tree models with a canopy, 10 mm cubes and a sampling probe for tracer gas. Four parallel rows of tree models at 100 mm intervals were aligned and the trunks of the trees were arranged in a staggered manner. An element of a model tree was 10 mm wide,

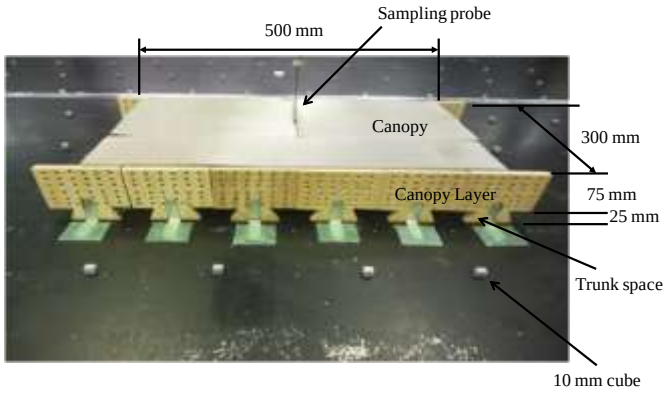

Fig. 1 Model trees in a wind tunnel.

consisting of a 75-mm-high canopy layer and a 25-mm-high trunk space. Thirty-six holes of 6 mm diameter were bored in the canopy layer with an opening ratio of 14 percent. Using these model trees, the

reduction ratio in wind velocity in the forest was found to be approximately 80 percent, which was similar to the result of the meteorological observation in the Ryukoku forest. Wire gauze of 12 meshes per inch was used to simulate the canopy. Propane was used as the tracer. The tracer gas was collected using a sampling probe and analyzed using a flame ionization detector. The sampling probe was positioned at the centre of the tree elements, as shown in Fig. 1. The release point of the tracer was situated on the 2000 mm windward side of the sampling point. The release heights were 0, 30, 60, 90, 120, 150 and 190 mm.

4. Results

Figure 2 shows the observed NO_2 concentration plotted with height from the forest floor in the Ryukoku forest. The observed NO_2 concentration decreased towards the forest floor from the top of the canopy throughout the year. The average ratio of NO_2 concentration inside the forest to that outside was approximately 70 percent.

The observed vertical distribution of NO_2 concentration outside the Ryukoku forest was almost uniform. It can be considered that this is because exhaust gas released from various heights is transported to the forest. The following integrated concentration was therefore estimated from the results of the wind tunnel experiment for each release height.

$$IC(z) = \int_0^H C(H,z)w(H)dH \Big/ \int_0^H w(H)dH \qquad (1)$$

where IC(z) is the integrated concentration of the tracer gas at the height z, C(H, z) is the concentration of the tracer gas at the height z for the release height of H, and w(H) is the weighting function. The values of w(H) were chosen so that a uniform vertical distribution of the tracer gas concentration outside the forest was obtained.

The results of the integrated concentration of the tracer gas are shown in Fig. 3. The broken and solid lines were obtained from the wind tunnel experimental results for a flat terrain and the model trees, respectively. The same value of the weighting function was used for both experiments. The concentration was normalised using the tracer gas concentration for a flat terrain at the height of the canopy top (z_{top}). Figure 3 also shows the observed result in the Ryukoku forest. Although wind tunnel experiments were conducted using very simple model trees, a similar reduction in the concentration of the tracer gas in the forest due to the wind break effect was observed. The reduction ratio was approximately 30 percent, which was almost the same as that observed in the Ryukoku forest. However, the decrease towards the forest floor from the canopy top was not obtained in the wind tunnel experiment.

5. Conclusion

A decrease in NO_2 concentration towards the forest floor from the top of the canopy was observed in the Ryukoku forest at Seta Hill in Shiga Prefecture, Japan. Within the forest canopy, the average NO_2 concentration observed was approximately 30 percent lower than that outside the forest. Fontan et al. (1992) and Krzyzanowski (2004) observed a similar decrease in the ozone concentration in the forest canopy layer and discussed the feature of such a decrease from the viewpoint of deposition on leaf surfaces, uptake by vegetation and chemical destruction.

The decrease in air pollutant concentration in the forest is due to not only the deposition of air pollutants onto leaf surfaces but also the effect of a tree wind break. Wind tunnel experiments cannot consider the effect of deposition, but can treat atmospheric transport and dispersion in tree models. The results of the wind tunnel experiment showed a similar decrease in the concentration of air pollutants inside the forest compared with that outside. However, the decrease in the concentration of air pollutants towards the forest floor from the top of the canopy was not observed in the wind tunnel experiment. From the above results, it is deduced that the low NO_2 concentration inside the forest compared with that outside is mainly due to the tree wind break effect and that the variation in NO_2 concentration with height from the forest floor is mainly due to the deposition of air pollutants onto leaf surfaces.

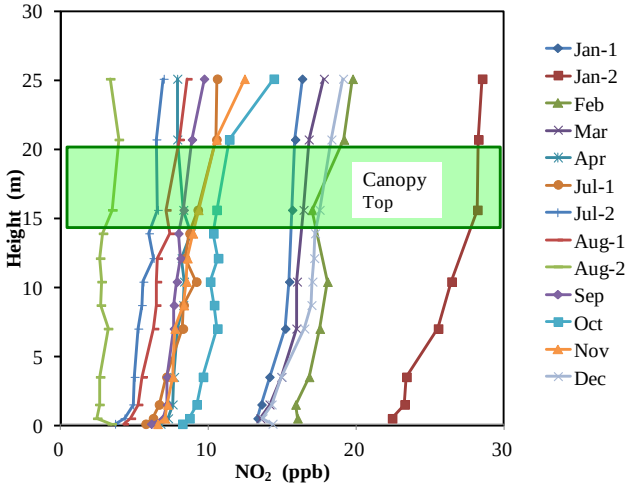

Fig. 2 Vertical distribution of NO_2 in Ryukoku forest. The legend shows the observation month in 2013.

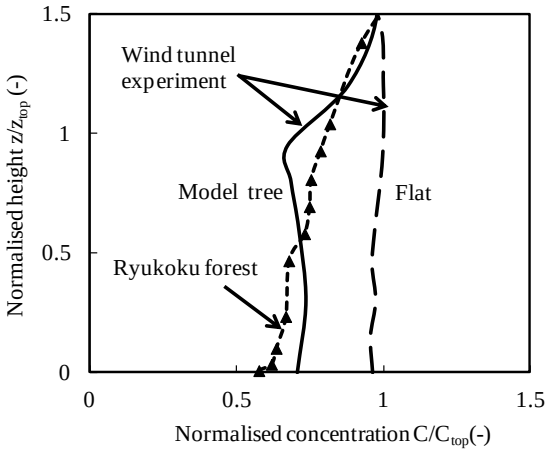

Fig. 3 Vertical profiles of integrated concentrations of tracer gas estimated from wind tunnel experiment and NO_2 profile observed in Ryukoku forest. C_{top} is the concentration for a flat terrain (outside the forest) at the height of the canopy top (z_{top}).

Acknowledgements

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