Evaluation of SO_2 deposition velocity and type of canopy resistance with Wesely parameterization model over a rice paddy in Thailand

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Abstract

A field measurement of SO_2 deposition flux was carried out over a canopy of irrigated rice paddy in the tropical climate in Chachoengsao province, central Thailand. The experiment was observed, from July to December 2007 covering seasonal period of the rainy (Jul.-Sep.) and the winter (Nov.-Dec.) seasons. The SO_2 deposition flux was determined by the Bowen ratio technique. Once the deposition flux was obtained, the deposition velocity of SO_2 can be evaluated. The average values of SO_2 deposition velocities in the rainy season were observed to be 0.37 cms^{-1} in daytime and 0.04cms^{-1} in nighttime. For the winter season, the deposition velocities were 0.68 cms^{-1} in daytime and 0.05 cms^{-1} in nighttime. The observed SO_2 deposition velocity was compared with Wesely's parameterization model in order to determine the corresponding type of the canopy resistances for the tropical region. In both seasons, the observed canopy resistance is closer to transitional spring with partially green short annuals type as predicted by the Wesely model.

Keywords: SO_2 dry deposition, Bowen ratio technique, Wesely parameterization model, Canopy resistance

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Introduction

Transport of SO_2 from the atmosphere to the earth's surface called acid deposition. It is one of the major air pollution which caused damaging effects on vegetation, aquatic life, materials and human health. Most researches on SO_2 dry deposition were conducted in North America and Europe (Erissman, 1994; Wesely and Hicks, 2000; Zhang et al., 2003)and parameterizations of SO_2 deposition velocity have been developed. However, only a few experiments on the acid deposition in Southeast Asia region were studied (Jitto and Kuhmmongkol, 2007; Matsuda, 2006). The purpose of this study is then to compare the applicability of existing dry deposition models with the direct field measurement of SO_2 flux for the Southeast Asia region. Parameters that affect the SO_2 flux are the climate, the growing cycle of vegetation and other properties of surface difference (canopy). For a study on the types of canopy, SO_2 deposition data were collected above a rice paddy filed.

Methods

Field site description

The experiment was conducted over a rice paddy, Chachoengsao province, central Thailand (13° 56′N 100° 56′E). The meteorological measuring instrument installing on a tower -5 m height consisted of a global radiation, net radiation, wind speed, temperature and relative humidity. The SO_2 concentrations were measured at two positions, 2 m. and 4 m. above the ground level using ultra-violet fluorescence analyzer. All data were taken from July to December 2007. The period from July to September was classified as the rainy season and November to December, the winter season.

Methodology

The deposition flux (F) was computed using the equation

$$F = D\Delta C \qquad (1)$$

where ΔC is the average vertical concentration difference, and D is the transfer coefficient, defined according to the Bowen ratio equation shown in equation 2. (Jitto and Kuhmmongkol, 2007; Matsuda, 2006; Monteith and Unsworth, 2001)

$$D_{1-2} = (R_n-G)/[\rho_a\lambda\Delta e_{1-2}(0.622)/p)+\rho_a c_p\Delta T_{1-2}] \qquad (2)$$

where R_n is the net radiation; G is the soil heat flux; ρ_a is the air density; λ is the heat of vaporization; P is the atmospheric pressure; C_p is the heat capacity of air; ΔT_{1-2} is the temperature difference; Δe_{1-2} is the water vapor difference. The dry deposition velocity (V_d) was calculated by equation 3.

$$V_d = F/C \qquad (3)$$

where C is the average value of SO_2 concentration. The canopy resistance (R_c) was obtained from the observed deposition velocity, the calculated aerodynamic resistance (R_a) and the quasi-laminar resistance (R_b). The R_a and R_b were calculated based on the meteorological measurements (Lamaud et al., 2002). R_c was calculated by equation 4.

$$R_c = 1/V_d-(R_a+R_b) \qquad (4)$$

The observed R_c above can be compared with the value calculated using the Wesely resistance model (Wesely,1989)

$$R_c = (R_s+R_m)^{-1} + (R_{lu})^{-1} + (R_{dc} + R_{cl})^{-1} + (R_{ac} + R_g)^{-1} \qquad (5)$$

where the first and second terms are resistances in the upper canopy, which include the stomatal (R_s), mesophyll (R_m) and outer surface resistances (R_{lu}), the third term is resistances in the lower canopy, which include the resistance to transfer by buoyant convection (R_{dc}) and the resistance to uptake by exposed surfaces (R_{cl}), and the fourth term is resistances to transfer (R_{ac}) and uptake (R_g) at the ground.

Results

Meteorological and evaluation of the transfer coefficient

Hourly average of the meteorological parameters and transfer coefficient are shown in table 1. R_n, G , Δe_{1-2} and ΔT_{1-2} are the parameters used to determine the transfer coefficient by Bowen ratio (Equation(2)). The result shows the average net radiation and soil heat flux were high during daytime (8:00-17:00) and decreased to zero or negative values during nighttime (18:00-7:00). Bowen ratio method is derived from the energy balance in the boundary layer, the value of transfer coefficient dependent on R_n-G input. At night or other conditions when R_n-G near zero, it is difficult to apply. Therefore, the appropriately time to apply the Bowen ratio technique is during 8:00 to 17:00. The average values of transfer coefficient were found to be 6.65 and 10.20 cms^{-1} in the rainy and the winter season, respectively.

The average values of SO_2 were 7.65 $ngcm^{-3}$ (daytime) and 5.38 $ngcm^{-3}$ (nighttime) in the rainy season. For the winter, the average SO_2 concentrations were 10.25 $ngcm^{-3}$ (daytime) and 6.44 $ngcm^{-3}$ (nighttime). The SO_2 concentrations increased in the winter season and decrease in the rainy season.

Table 1. Meteorological parameters and average SO_2 concentration

Parameters	Rainy season		Winter season	
	Day Time	Night Time	Day Time	Night Time
SO_2[$ngcm^{-3}$]	7.65	5.38	10.25	6.44
Net radiation [Wm^{-2}]	291.6	-25.0	434.6	-37.0
Soil heat flux [Wm^{-2}]	27.9	-18.0	20.7	-30.5
Vapour pressure gradient[mmHg]	1.44	-0.56	1.37	-0.40
Temperature difference [°C]	0.68	-0.42	0.78	-0.34
Wind speed [ms-1]	1.8	0.4	2.0	0.6
[cms-1]	6.65	0.50	10.20	0.55

This caused by a high turbulence in the winter and dilution in rain during the rainy season.

Deposition velocity of SO_2

The diurnal variation SO_2 deposition velocity is shown in Figure1 in hourly average. The SO_2 deposition velocity was evaluated by Equation (1),(2) and (3). The result showed that V_d was in large variation during the day. The average values of V_d were 0.37 cms^{-1} (daytime) and 0.04cms^{-1} (nighttime) in the rainy season and 0.68 cms^{-1} (daytime) and 0.05 cms^{-1} (nighttime) in the winter season. In both seasons was high during the day-time when the incoming solar radiation was intense. In the same way, in the winter season was higher than the rainy season. It caused by the same effect of high intensity of the incoming solar radiation as shown in table 1.

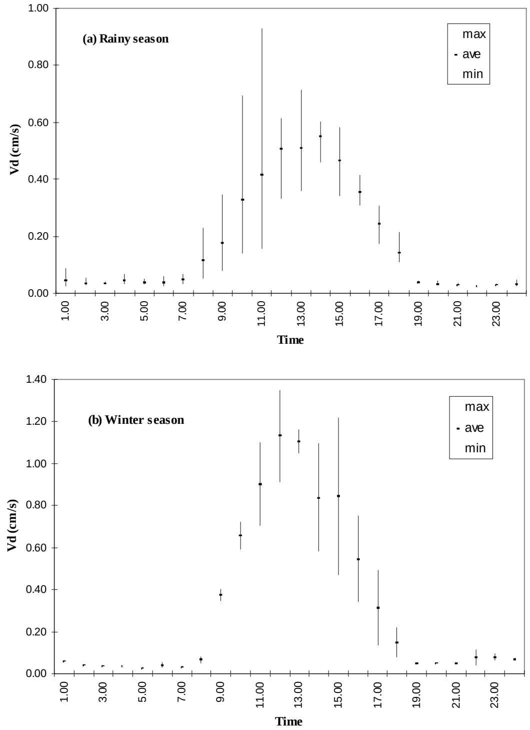

Figure 1. Hourly average of SO_2 deposition velocity and time of the day during a period of: a) rainy season b) winter season

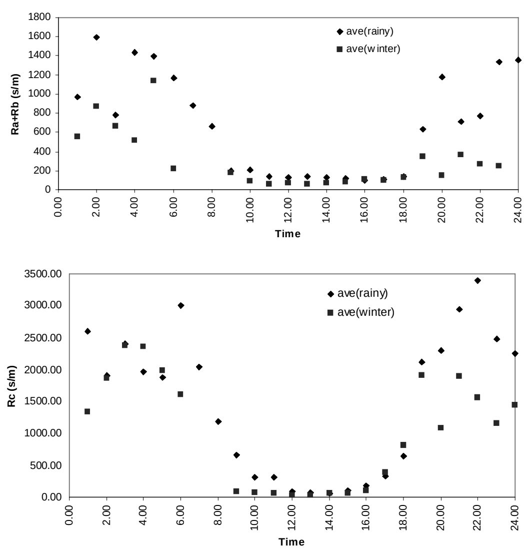

Figure 2. Average diurnal variations of observed $R_a + R_o$ and observed R_c in the rainy and winter season

Canopy resistance of SO_2

Average duration variation of $R_a + R_o$ and observed R_c (computed by Equation (4)) are shown in Figure 2. The result showed that the observed decreased from the value higher than 1,500 in the morning to the minimum value during the midday. The values were in between 50 sm^{-1} in the rainy season and 30 sm^{-1} in the winter season. After sunset, R_c was increased to the maximum at night. $R_a + R_o$ were also decreased in the daytime, the same pattern as the observed R_c. The high value of V_d in daytime depends on a strong uptake of SO_2 by the rice field canopy and a decreasing resistant of $R_a + R_o$. The variability of R_c was effected by the vegetation stomata activity. During daytime, SO_2 molecules diffuse through the open stomata by photosynthesis process. This process reduced the canopy resistant (R_c) and hence increased the deposition rate. At night, the stomatal close and R_c increased significantly.

Table 2. A comparison of average observed canopy resistance R_c (Eqs.4) and the R_c predicted by Wesely model (Eqs.5)

Parameters	Rainy season		Winter season	
	Day Time	Night Time	Day Time	Night Time
observed [sm^{-1}]	279	2319	170	1715
R_c_1 predicted [sm^{-1}]	118	343	138	644
R_c_2 predicted [sm^{-1}]	610	777	364	1084
R_c_3 predicted [sm^{-1}]	618	797	324	1076
R_c_4 predicted [sm^{-1}]	580	758	281	1042
R_c_5 predicted [sm−1]	205	432	194	838

The average observed R_c and R_c predicted by Wesely's parameterization (computed by Equation (5)) was shown in Table 2. The Wesely's parameterization for R_c, baseline resistances, are set for 5 categories of seasons defined as (1) midsummer with lush vegetation, (2) autumn with unharvested cropland, (3) late autumn after frost no snow, (4) winter, snow on ground and subfreezing, (5) transitional spring with partially green short annuals. It was found that during daytime the observed R_c were closer to transitional spring with partially green short annuals type (category 5). However, at nighttime the observed R_c s do not match all of 5 categories. The R_c values determined by the Wesely's model were lower than the Bowen ratio calculations. The Bowen ratio was dependent on the energy in put by solar radiation but the Wesely's model was highly dependent on wind speed (Matsuda et al., 2001). Wind speed during nighttime is low, as shown in table 1.

Conclusions

SO_2 dry depositions were measured over rice paddy field in Chachoengsao province, central Thailand, in the rainy and winter seasons from July to December 2007. The experimental period covers the growing cycle of rice paddy field. The average values of SO_2 deposition velocities were found higher in the winter season than the rainy season. Both R_a + R_o and observed R_c were decreased in daytime. During daytime, the observed R_c in both seasons were in the vicinity of transitional spring with partially green short annuals type determined by the Wesely resistance model. At night the observed R_c do not fall in any all of 5 categories. This study showed that the parameterization of non-stomatal (nighttime) resistance needed modification over rice paddy field in Southeast Asian region.

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References

Erissman, J.W. 1994. Evaluation of a surface resistance parameterization of sulphur dioxide. **Atmospheric Environment**. 28: 2583-2594.

Jitto, P., Kuhmmongkol, P. 2007. Dry deposition velocity of sulfur dioxide over rice paddy in the tropical region. **Atmospheric Research**. 85: 140-147.

Lamaud, E., Carrara, A., Erunet, Y., Lopez, A., Druihet, A. 2002. Ozone fluxes above and within a pine forest canopy in dry and wet conditions. **Atmospheric Environment**. 36: 77-88.

Matsuda, K., Aoki, M., M., Zhang, S.D. 2001. Dry deposition velocity of sulfur dioxides on a red pine forest in Nagano Japan. **Journal of Japan Society for Atmospheric Environment**. 37: 387-392.

Matsuda, K., Watanabe, I., Wingpud, V., Theramongkol, P., Ohizumi, T. 2006. Deposition velocity of O3 and SO2 in the dry and wet season above a tropical forest in northern Thailand. **Atmospheric Environment**. 40: 7557-7564.

Monteith, J.L. and Unsworth, M. 2001. **Environmental Physics, 2nd ed, Butterworth-Heinemann**. Oxford, pp.51-385.

Wesely, M.L. 1989. Parameterization of surface resistance to gaseous dry deposition in regional scale, numerical model. **Atmospheric Environment.** 23:1293-1304.

Wesely, M.L., Hicks,B.B., 2000. A review of the current status of knowledge on dry deposition. **Atmospheric Environment.** 32: 2261-2282.

Zhang, L., Brook, J.R.,Vet, R. 2003. Evaluation of a non-stomatal resistance parameterization for SO_2 dry deposition. 37: 2941-2947.