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SHORT COMMUNICATION

THE SENSITIVITY OF REGIONALLY AVERAGED O_3 AND SO_2 CONCENTRATIONS TO ADOM DRY DEPOSITION VELOCITY PARAMETERIZATIONS

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Abstract—The influence of three different surface resistance formulations upon the resulting grid-averaged dry deposition velocity and the concentrations of O_3 and SO_2 calculated using the Acid Deposition and Oxidant Model (ADOM) has been investigated. Four ADOM simulations of the O_3 and SO_2 concentrations were compared with each other and the observations. The results show that two of the resistance formulations can decrease the original ADOM area-averaged dry deposition velocity by as much as 50% and increase the corresponding concentration by as much as 37% for O_3 and SO_2. However, all versions of the ADOM considerably underpredict the concentrations, implying weaknesses in ADOM that are not related to dry deposition. Wet surfaces appeared to have little influence on the estimated dry deposition velocity and concentration of O_3 but had a strong influence on those for SO_2.

Key word index: Dry deposition, resistance, O_3, SO_2, Eulerian model simulations, observations.

1. INTRODUCTION

There are studies which deal with the evaluation of the comprehensive Eulerian air quality model known as the Acid Deposition and Oxidant Model or ADOM (Venkatram *et al*., 1988; Misra *et al*., 1988; Padro *et al*., 1991; Hansen *et al*., 1991). This model includes a dry deposition module which is based on the electrical resistance analogy (Pleim *et al*., 1984; Padro *et al*., 1991). The present study investigates estimates of the regionally averaged deposition velocity and concentration obtained from ADOM. Padro *et al*. (1991, 1992) have investigated this module when it was isolated from ADOM and tested it, using O_3 measurements collected over a fully leafed deciduous forest during the summer of 1988. The module's estimates of the dry deposition velocities (V_d) were about 70% larger than the observed values, a discrepancy that resulted from the inadequate representation of the canopy resistance. This resistance was modified (Padro *et al*., 1991) to include increases in the stomatal, cuticle and ground resistances and decreases in the mesophyll resistance and the leaf area index (LAI). The stomatal resistance was increased by reducing the value of a parameter (B_{max}) that determined the solar radiation influence on stomatal opening. These modifications reduced the overestimated V_d values of O_3 by about 35% and also reduced the large estimates of the SO_2 V_d values (Padro *et al*., 1991, 1992). The remaining 35% overestimation could not be corrected within the limitations of the "Big Leaf" approximation that is employed in ADOM.

Although these modifications (Table 1) were based on comparisons with measurements collected over a deciduous forest, they are assumed to have a more general application for grid averaged values for O_3 and SO_2 in ADOM. The present study investigates estimates of daily averages of V_d and surface concentrations of O_3 and SO_2 obtained from four distinct model simulations. These consist of: (1) the original dry deposition configuration in ADOM as reported in Pleim *et al*. (1984), (2) the modified ADOM (Table 1), which excludes treatment of wet surfaces, (3) the modified ADOM, which includes a formula for wet surfaces and is assumed to apply equally to surfaces wetted by rain or dew (Padro *et al*., 1991), and (4) the modified ADOM that includes the surface resistance parameterization of Wesely (1989). ADOM computes the daily average V_d over each land-use type within a grid square and arithmetically averages the area weighted land-use type values to yield a grid average V_d. The grid values are then averaged to yield

Table 1. Values for model parameters

	Model					Modified model				
Species	r_m	r_{cut}	R_g	B_{max}	LAI	r_m	r_{cut}	R_g	B_{max}	LAI
O_3	4.0	9.0	2.7	10.0	6.0	0.0	16.0	5.3	2.5	5.0
SO_2	0.0	17.0	5.0	10.0	6.0	0.0	30.0	10.0	2.5	5.0

r_m is leaf mesophyll resistance ($s\,cm^{-1}$).
r_{cut} is leaf cuticle resistance ($s\,cm^{-1}$).
R_g is bulk ground resistance ($s\,cm^{-1}$).
B_{max} is stomatal opening parameter (μm) (see Padro *et al*., 1991).
LAI is leaf area index.

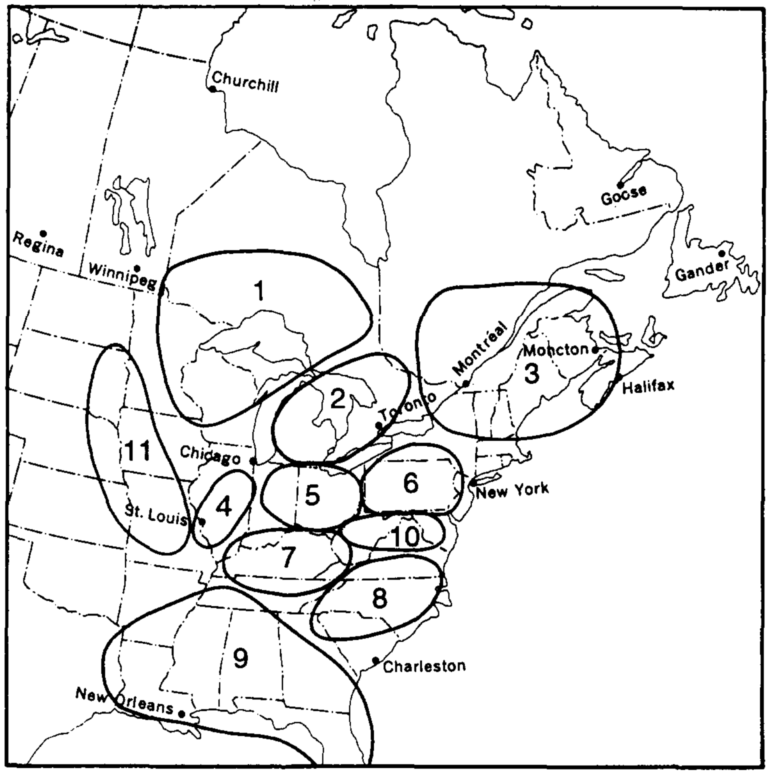

Fig. 1. The surface network of EMEFS, divided into 11 regions. Each region includes a different number of stations, as listed in Table 1.

average deposition velocities for each region (Fig. 1), which are compared among the three models. The resulting concentrations are compared with the observations. The model was integrated for the period 25 July–8 August (Julian days 207–221) on the CRAY-XMP computer.

Wesely's (1989) parametrization was changed: (1) to reduce the 11 land-use categories to the 8 that are employed in ADOM and (2) to apply the dew formula for both dew and rain since ADOM does not distinguish between them. In ADOM, the canopy wetness is expressed in percent of local area (Padro, 1991). In contrast, Wesely's (1989) formula applies only to a fully wet canopy. Accordingly, a fully wet canopy was arbitrarily assumed to occur when the canopy wetness exceeded 40%.

2. DATA

Deposition velocity (V_d) measurements for O_3 were made over a fully leafed mixed deciduous forest located on the Canadian Forces Base Borden (44°19′N and 80°56′W) for 55 days during July and August 1988 (Padro *et al.*, 1991). These measurements were compared with the appropriate grid average ADOM V_d, calculated using the three different parameterizations. Although these site-specific V_d data are in general not expected to be representative of a grid square, their daily averages may be more representative, especially for a grid square that is primarily covered by vegetation, which is known to dominate the V_d of O_3 and SO_2. Each of the grid squares (33*33) in ADOM, having the size of 127 km by 127 km, includes a maximum of 8 land-use types. About 80% of the land surface in the ADOM geographic domain is covered with vegetation.

Observations of surface concentrations ($\mu g\ m^{-3}$) for O_3 and SO_2 were collected as part of a two-year Eulerian Model Evaluation Field Study (EMEFS) and are reported in Hansen *et al.* (1991). These were obtained from measurement sites within the ADOM domain (Fig. 1), which was divided into 11 geographical regions. For each day, regional averages were calculated for the observed and simulated O_3 and SO_2 concentrations for the period 25 July–08 August 1988. An example of the comparison between modelled and measured area average concentrations is described in this paper.

3. RESULTS AND DISCUSSIONS

Figure 2 illustrates the time series of the daily averaged O_3 concentrations for Region 6 obtained from ADOM, the

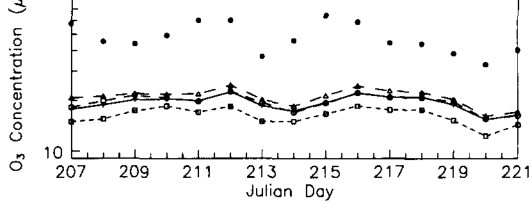

Fig. 2. Time series of the daily averages of the estimated O_3 concentrations using: (1) the original ADOM, (2) the modified ADOM, excluding surface wetness, (3) the modified ADOM, including surface wetness, (4) the Wesely formulation, and the (5) observations for region 6 for 25 July–08 August 1988 (Julian days 207–221).

Table 2. Daily average V_d decrease (%) due to modifying ADOM (excluding wetness) and the resulting increase (%) in concentrations of O_3 and SO_2 for Region 6

Day	O_3 concentration (% increase)	O_3 V_d (% decrease)	SO_2 concentration (% increase)	SO_2 V_d (% decrease)
July 28	10	32	14	50
July 29	17	38	18	55
July 30	22	40	22	56
July 31	24	41	23	52
Aug. 01	15	32	16	48
Aug. 02	17	55	15	51
Aug. 03	19	39	21	53
Aug. 04	19	41	18	56
Aug. 05	19	42	17	57
Aug. 06	24	42	19	52
Aug. 07	25	38	25	56
Aug. 08	15	34	16	57

modified ADOM (excluding and including surface wetness) and the observations. All model simulations yield values that are much below the observations but the modified ADOM shows that the concentrations can increase by as much as 25% and the corresponding V_d can decrease by as much as 55% (Table 2), when compared to the original dry deposition configuration. The modified formulation has been known to reduce the dry deposition velocity over vegetative surfaces (Padro *et al.*, 1991). The relationship between the changes of the ADOM V_d and the concentration is not linear. For O_3, the modified ADOM concentration values over a wet surface are about the same as those over a dry surface. Although there are significant differences in the estimates of the concentrations among the various modules, compared to the observations these differences appear to be small. They cannot, however, be ignored because of the possibility that they may be additive to other improvements in the ADOM formulation.

The O_3 concentrations obtained from the ADOM version, which includes the Wesely's surface resistance parameterization, is also shown in Fig. 2. Although these values are larger than ADOM by about 35%, compared to the observations they are still much smaller. It appears that other mechanisms in ADOM need to be addressed to explain the apparent lack of agreement between the simulated and the observed O_3 concentrations. After such a correction is made, the improvements effected by the new dry deposition modules would be better appreciated.

In the case of the SO_2 concentrations over a dry surface, all the simulations also show values that are substantially less than the observations for Region 6, but the modified ADOM shows some improvement when compared to the original configuration (Fig. 3). Similar to the case of O_3, these improvements show as much as a 57% decrease in the V_d and a 25% increase in the concentration (Table 2). For cases when the surface was wet, there were days when the V_d increased by as much as 103% and the concentration decreased by as much as 37% (not shown). In the case of the Wesely formulation the concentrations of SO_2 are at times indistinguishable from those calculated with the original ADOM formulation. This implies that Wesely's resistances may not be sufficiently large. Although the impact of the different deposition velocity formulations on the concentration is large, the differences among them do not show up clearly in Figs 3 and 4 because the estimates from the three modules are considerably smaller than the observations. These differences can be better illustrated with an example of grid point estimates of V_d for the various models.

Figure 4 shows an example of the large differences in the grid-averaged V_d that can occur among the different models for the ADOM grid point (16, 19), chosen because of its proximity to the Camp Borden site. The measurements for this site are also included for comparison. An explanation that in this case a comparison between the grid-averaged estimate and the site measurement has some validity was given earlier. The V_d values from the modified ADOM show on the average the best agreement with these measurements. The lower V_d values obtained from the Wesely model are due to the large surface resistance included in that parameterization.

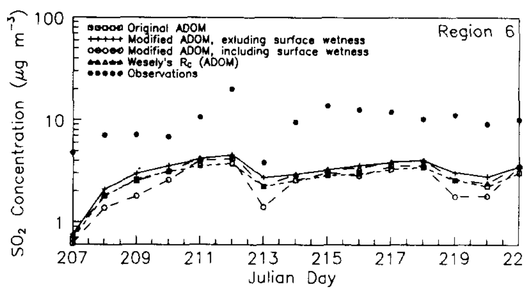

Fig. 3. Same as in Fig. 2, except for SO_2.

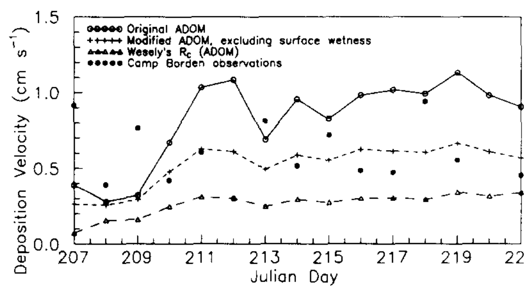

Fig. 4. Time series of the O_3 V_d at grid point (16, 19) estimated from the three modules and their comparison with the measurements from Camp Borden for 25 July–08 August 1988 (Julian days 207–221).

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