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Project Summary

Comparison of the RADM Dry Deposition Module with Site - Specific Routines for Inferring Dry Deposition

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The computer module for calculating dry deposition velocities in the Regional Acid Deposition Model (RADM) has been modified to operate with site-specific data provided by measuremenl stations such as CORE (COre Research Establishment, for dry deposition) satellite sites. Data collected during 1986 at seven widely separated sites in the eastern United States were used to estimate weekly averages of deposition velocities for SO_2, O_3, HNO_3, and SO_4^{2-}. Similar calculations were made with the inferential technique that was developed at Atmospheric Turbulence and Diffusion Division of the National Oceanic and Atmospheric Administration's Air Resources Laboratory. Comparison of results obtained with the two techniques indicate that some systematic differences exist, even when the module uses distributions of landuse types that match as closely as possible the observed vegitation coverages used in the inferential technique. When one ignores the systematic differences that could be removed by minor changes in the algorithms for computing resistances to deposition, the relative uncertainties for $SO_2$and O_3 deposition velocities are approximately ±30%. Likewise, the relative uncertainties corresponding to nonsystematic differences in the deposition velocities for HNO_3 and SO_4^{2-} are about ±30% and ±50%, respectively. Use of the landuse map to extrapolate to areas as large as RADM qrid cells (approximately 8O km square) around the measurement sites produces weekly averages of deposition velocities for SO_2, O_3, and SO_4^{2-} that are within ±20% of those computed for the local site and approximately ±30% for HNO_3, if one avoids landuse types such as urban and water areas that are nonrepresentative and have very different characteristics from the measurement sites. These estimates do not represent true uncertainty or accuracy because of unknown sources of error possible in the input data and deposition velocity algorithms for nonuniform surfaces.

This Project Summary was developed by EPA's Environmental Monitoring Systems Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The dry deposition module of the Regional Acid Deposition Model (RADM) is used to compute the dry deposition velocities (downward flux divided by concentration at a specified height) for SO_2, SO_4^{2-}, O_3, HNO_3, and other compounds. With its computerized landuse map, the module can provide estimates of the deposition velocities for a given set of meteorological and surface conditions that are representative of an area located anywhere in the contiguous United States and nearby locations. As part of this project, the module uas been modified to accept data on meteorological and surface conditions observed at measurement stations rather than inputs computed with

RADM. The purpose of these modifications was to make site-specific estimates of dry deposition velocities, and compare them with results from the site-specific inferential technique that has been developed at the Atmospheric Turbulence and Diffusion Division (ATDD) of NOAA's Air Resources Laboratory. Goals of the comparisons include estimating the relative uncertainties of the two techniques, suggesting improvements, and examining the ability of the modified module to provide estimates of dry deposition for expanded areas around the measurement sites.

The observational data used in these analyses were collected with ATDD instruments during 1986 at the seven sites listed in Table 1. The sites identified are either CORE (COre Research Establishment, for dry deposition) stations or CORE satellite stations. The data set itself consists of hourly averages of wind speed, the standard deviation of the horizontal wind direction, solar irradiation, air temperature, relative humidity, and surface wetness from a sensor that indicates the presence of moisture from dewfall and rainfall. Other data include one observation per week of the fraction of full leaf cover, from which the seasonal categories used in the module are derived, and the information given in Table 1 describing the types and amounts of vegetative species present at the local site. The landuse distributions for the local site are determined from the relative amounts of these species, while the distributions for the RADM grid squares (approximately 80 km square) encompassing each site are derived entirely from the computerized RADM landuse map. Although the deposition velocities (v_d) are computed for every hour, the results considered here are averages over periods of at least one week.

Results and Conclustions

The dry deposition module of the RDAM has been successfully adapted to use site-specific data obtained at dry deposition stations such as the CORE satellite sites. The module was originally written to use more complete local micrometeorological information than is included in the parameters listed above, so considerable manipulation of the coding was needed in the RADM module in order to accept these inputs. Perhaps the least exact formaulations in the modified module are those that deal with estimating atmospheric stability, but uncertainties introduced by the compromised equations are probably overshadowed by the fact that most of the sites are located in areas with surface properties insufficiently uniform, or with terrain insufficiently flat, to allow very precise micrometeorological calculations. The algorithms in the modified module that are used to compute crucial parameters such as aerodynamic resistance above the surface and friction velocity are quite similar to those used in the inferential technique. Some notable differences exist, however. One is that the modified module attempts to mimic the RADM module by computing changes in the gas-phase resistances for surfaces identified by landuse types different from the dominant landuse type for the local site. At most of the sites, this alteration produces smaller aerodynamic resistances and larger friction velocities averaged over the areas surrounding the site, and thus increases the deposition velocities for HNO_3. The deposition velocities for other substances do not seem to be significantly affected, because their surface resistances are usually much larger than the aerodynamic and gas-phase sublayer resistances (which depend on friction velocity).

The alogrithms used in the modified module to compute the bulk surface resistance, usually the most important term for determining deposition velocities, are the same as those used in the RADM module. Some changes had to be made in the

Table 1. *Site names, locations, predominant surface vegetation (within one kilometer), and landuse types assumed with the modified module*

General Location (deg lat., long.)	*Site ID*	*Local Surface Vegetation and Landuse Types* (percent coverage)*
Argonne National Laboratory, IL 41.70 N, 87.98 W)	*ARG*	*grass (50), white oak (50)* *local site: 2(50), 4(50)* *RADM square: 1(23), 2(62), 4(2), 7(13)*
Bondville (Champaign), IL (40.05 N, 88.37 W)	*BON*	*maize (50), soybeans (50)* *local site: 2(100)* *RADM square: 1(2), 2(98)*
Oak Ridge, TN (35.96 N, 84.28 W)	*OAK*	*white oak (70), loblolly pine (30)* *local site: 4(70), 5(30)* *RADM square: 1(3), 2(30), 4(64), 7(3)*
Panola State Park, GA (33.63 N, 84.18 W)	*PAN*	*Loblolly pine (50), chestnut and red oak (50)* *local site: 4(50), 5(50)* *RADM square: 1(13), 2(22), 4(28), 5(6), 6(29), 7(2)*
Pennsylvania State Univ., PA (40.72 N, 77.92 W)	*PSU*	*maize (30), white oak (30)* *local site: 2(50), 4(50)* *RADM square: 1(4), 2(20), 4(73), 5(3)*
West Point, NY (41.35 N, 74.05 W)	*WST*	*maple (60), white oak (30)* *local site: 4(100)* *RADM square: 1(41), 2(3), 4(28), 6(2), 7(26)*
Whiteface Mountain, NY (44.39 N, 73.86 W)	*WHT*	*white birch (70), maple (10)* *local site: 4(100)* *RADM square: 1(1), 2(6), 4(28), 5(10), 6(43), 7(12)*

*Landuse types specified are [1] urban land, [2] agricultural land, [4] deciduous forest, [5] coniferous forest, [6] mixed forest including wetland, and [7] water, both salt and fresh water.

parameterizations of the SO_4^{-2} sublayer resistance in air, which strongly controls SO_4^{2-} deposition velocity, but the changes conform with the interpretation of the field experiments on which the parameterizations are based. The inferential technique is configured somewhat differently and appears to overestimate the deposition velocity for SO_4^{2-} in some situations. The module, however, tends to underestimate when the standard deviation of the horizontal wind direction is not measured very well.

The most striking difference between the results of the module and the inferential technique is the much smaller estimates made with inferential technique for SO_2 and O_3 deposition velocities during nonsummer conditions. These are probably underestimates caused by overly restrictive assumptions on the surface resistances of bare soil and sparse vegetation during nonsummer seasons, which could easily be adjusted by changing the values of a few numerical coefficients used in the inferential technique.

While the algorithms for surface resistance in the modified module are based on a more complex and versatile set of multiple surface resistances to various portions of the surface than the algorithms used in the current version of the inferential technique, the module is strongly limited by the fact that the surface can be described by at most 11 landuse types. The inferential technique employs description of vegetation by species and tailors the surface resistances more precisely than the module to describe the physiological responses to environmental parameters such as solar irradiation and temperature. An additional feature that may be desirable is a factor to take into account soil moisture stress on the stomatal resistances of healthy vegetation during the daytime, because the current version of the inferential technique assumes no soil moisture stress and the module is effectively tuned to a small amount of moisture stress. As a result, the deposition velocities of substances such as SO_2 and O_3 that are strongly influenced by stomatal resistances are slightly larger when computed by the inferential technique than with the modified module.

For the weekly averages of deposition velocities computed for 1986 at the seven sites, the inferential technique and the modified module produce estimates within about $\pm30\%$ of each other for SO_2 and O_3, if we neglect strong systematic differences such as those that occur during nonsummer conditions at surfaces with bare soil or sparse vegetative canopies. Likewise, the differences for HNO_3 and SO_4^{2-} deposition velocities are usually about $\pm30\%$ and $\pm50\%$, respectively. These relative uncertainties could probably be reduced somewhat if the suggestions made above were adopted.

Estimates of deposition velocities over large areas are easily computed with the modified module by use of the appropriate landuse distributions. Of course, if the areas are very large, the observations of meteorological conditions at the measurement stations might not be sufficiently representative. Some trial runs involving the 20-km squares of the landuse map cell and the 80-km RADM cells at the seven measurement sites show that the estimates of weekly averaged deposition velocities for SO_2 ,O_3 and SO_4^{2-} are fairly sensitive to the amounts of urban and water areas included in landuse distributions. Aside from this effect, the deposition velocities calculated for these three substances over the RADM grid cells are usually within $\pm20\%$ of those for the local site descriptions. These limits should not be taken as generally valid at sites other than the seven examined in this study, because different meteorological conditions and altered combinations of landuse types could cause larger changes in deposition velocities. For HNO_3, minor changes in the assumed landuse distributions often cause rather large changes, easily $\pm30\%$, in deposition velocities.

We conclude that the differences in deposition velocity estimates caused by scaling from local site conditions to RADM grid cells are often slightly smaller than the relative uncertainties of the deposition velocities estimated with the modified module and the inferential technique. Hence, inferences of deposition velocities for the local conditions at carefully chosen sites appear to be reasonably representative of larger areas extending at least to sizes of RADM grid squares. Nevertheless, adjustments for changes in surface conditions are clearly desirable, and extrapolation to types of surfaces that have notably different properties can be made only at the cost of considerably greater uncertainty. By use of a computerized landuse map or, preferably, a more detailed description of surface conditions, one should be able to estimate weekly averaged dry deposition amounts for sulfur, nitric acid, and ozone to within about $\pm30\%$ over some fairly large areas.

The above number of 30% is not the true uncertainty or accuracy. An assessment of accuracy would require experiments designed specifically for dry deposition, because a number of factors can cause additional uncertainty. For example, one must determine how representative the local meteorological measurements actually are. Relatively low wind speeds measured at OAK and PAN suggest that proper exposure of instruments in a forested, hilly area might be difficult. In addition, measurements taken at sites not representative of any one surface or influenced by local aerodynamic obstacles might not be suitable for application of the algorithms used in the inferential and the module approaches. Finally, these algorithms do not directly consider the effects of surface nonuniformities in the area considered, including hills, isolated surface irregularities, and edges associated with changes in height of surface cover. The aerodynamic resistances could be strongly altered by surface nonuniformities, and stomatal resistances could be altered by varying degrees of shading of sunlight by hills and other vegetation.

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The complete report, entitled "Comparison of the RADM Dry Deposition Module with Site-Specific Routines for Inferring Dry Deposition," (Order No. PB 88-238 191/AS; Cost: $19.95, subject to change) will be available only from:
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