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RAM 1.0 Software for Gaussian-Plume Multiple Source Air Quality Simulation

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Abstract: This study presents a developed software in environmental engineering, namely RAM 1.0 (RAM: Regulatory Air Model), adopted completely Graphical User Interface (GUI) technique, for operating in various Windows-based microcomputers. RAM 1.0 software consists of the improved RAM Model and RAM Algorithm as well as developed RAM 1.0 Graphical User Interface, respectively. RAM Model takes into account different ambient characteristics, meteorological conditions, receptor information and point/area source emission parameters. RAM 1.0 Interface has strong ability of post-processing for graphically illustrate calculated results. By using RAM 1.0 Software, it is able to simulate atmospheric pollutant dispersion, caused by the emissions of up-to 250 point sources and/or 100 area sources in level or gently rolling terrain for a period from one hour to one year. Both urban and rural zones can be calculated. The user-specified receptor grid may contain up-to 9000 nodal points, through which model-calculated concentration fields can be expressed by various refined two- and three-dimensional graphics, which greatly help the user to quickly analyze the regional air quality.

Key words: Regulatory air model, regional air quality, graphical user interface technique

INTRODUCTION

Smoke being emitted into air from a chimney is a classical case that causes air pollution. The rising process of smoke critically depends on atmospheric ambient, meteorological conditions, emission parameters, such as the action of atmospheric stratification, initial emission momentum and temperature, wind direction and speed as well as turbulent behaviors, and so on. If there exist a number of emission sources, for example, a lot of sources with different types (point source and/or area source) in urban and/or rural zones, smoke rising and diluting process turn into more complex. Engineers and environmentalists are greatly interesting into the smoke dilution process and scope, as pollutant dispersion in air may seriously affect regional air quality, and has been widely concerned by human society.

This study presents RAM 1.0 software, developed by the authors. This software, operating in various windows-based microcomputers, consists of RAM Model, RAM Algorithm and Code and RAM 1.0 Graphical User Interface System as well as RAM 1.0 help system, respectively. RAM Model and Algorithm is originally coded in Fortran Language by EPA (U. S. Environmental Protection Agency) in 1987, which are a numerical tool for Gaussian-plume multiple source dispersion analyses, and have been recently improved by the authors. The improved executive file, RAM 1.0.EXE, can be easily invoked by the developed RAM 1.0 Graphical User Interface System. RAM 1.0 Software calculates short-term pollutant concentrations from multiple point and/or area sources at a user-specified receptor grid in level or gently rolling terrain. Pollutants considered are relatively non-reactive, such as sulfur dioxide (SO_2) and suspended particulates. Both urban and rural situations can be simulated.

Original RAM Model merely has the capability to generate maximum 180 receptors. The developed RAM 1.0 Interface can generate a rectangular grid system with the receptor number up to 9000. This function is very useful while the user needs to generate detailed height and surface plots as well as contour image maps at receptors. RAM 1.0 Interface can directly plot, store and print various fine 2- and 3-D graphics for input data and output results, which include the fine graphics for describing contour lines (2-D, both in black and color, and image maps); geometric positions and emission rates of point and/or area sources (3-D); concentrations at receptors for specified emissions (3-D, both in black and color); wires (3-D, both in black and color), and surfaces (3D, both without and with wires), respectively.

Resume of RAM Model: The main characteristics of original RAM Model can be simply listed as follows:

Recommendation Uses:

* Emissions generated by multiple point sources or area sources, or by both;
* Level or gently rolling terrain in rural and urban zones;
* Distance of inferior transport up to 50 kilometers;
* Calculated periods from one hour to one year;

* Estimation of air quality.

Input Data:

* Meteorological data: ambient air temperature, wind direction, wind speed, mixing height, stability class at the hour of measurement and for each calculated hour, also include anemometer height and power law wind profile exponents for each stability class.
* Emission source data: for point sources, include sources' locations (coordinates), emission rates of pollutants, stack inside diameters and physical heights, emitting gas temperatures and gas exit velocities, respectively. Area sources require locations, side length, heights and emission rates.
* Receptors' data: names and coordinates for the receptors up to 180; or up to five distances, in which RAM Model will generate 36 receptors for each distance entered, or a honeycomb array of receptors (also up to 180).

Outputs of Results: They are listed by following order: options and source information; receptor information; meteorological parameters; model-calculated concentrations in micrograms per cubic meters for each hour for significant sources and for the summaries; and the concentrations for the average period. Also various other output files can be obtained.

Pollutant Types: Pollutants considered are relatively non-reactive, such as sulfur dioxide (SO_2) and total suspended particulates. Pollutants other than sulfur dioxide and particulates may also be substituted.

Plume Behaviors: RAM Model uses Briggs' plume-rise equations to estimate plume final rise heights and effective heights of emission. Fumigation phenomenon is not included.

Horizontal Winds are constant and uniform for the period of one hour. Separate urban and rural default wind-profile exponents are used in the model, when they have not been provided on input.

Vertical Winds are not considered in the Model.

Horizontal Dispersion: The dispersion parameter values representative for urban area are those recommended by Briggs. Six classes of stability can be used.

Vertical Dispersion: The dispersion parameter values representative for open countryside are the Pasquill-Gifford curve.

Removal or Chemical Reactions: RAM can approximate the transformation of a pollutant primarily as a function of time resulting in loss of that pollutant throughout the entire depth of each plume. This is accomplished by an exponential decrease with travel time from the source.

Resume of RAM Algorithm: Gaussian plume model is well performed in various atmospheric dispersion investigations, with a great applicability in practice [1]. The Gaussian model admits the dispersion starting from a continuous source, along with a plume, to which a mathematical formulation has been developed that allows us to calculate the pollutant concentration at a certain special position. Except for the geometric dimension of a chimney, Fig. 1 indicates three space positions **P**(x, 0, 0), **Q**(x, 0, z) and **R**(x, y, z), where the concentrations of pollutant can be determined, and also the 3-D Cartesian co-ordinary system, under which the model of pollutant plume distribution were established.

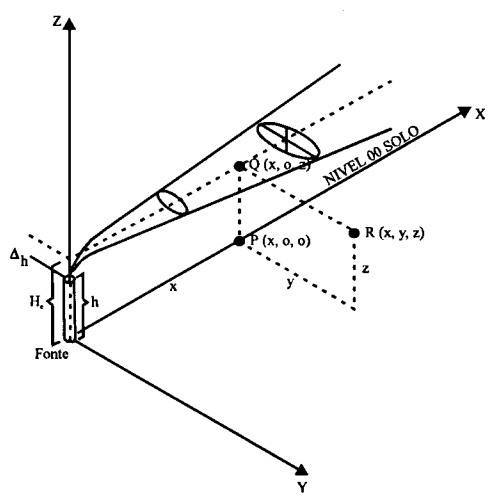

Fig. 1: Scheme of Atmosphere Dispersion

The pollutant concentration at any point **R**, with a certain distance apart from one emission point source, is given by the following expression [2]:

$$C(x,y,z)=\frac{Q}{2\pi d_y d_z v}\left\{e^{\left[-\frac{1}{2}\left(\frac{y}{d_y}\right)^2\right]}\right\}\left\{e^{\left[-\frac{1}{2}\left(\frac{z+H_e}{d_z}\right)^2\right]}+e^{\left[-\frac{1}{2}\left(\frac{z-H_e}{d_z}\right)^2\right]}\right\} \quad (1)$$

where C - pollutant concentration ($\mu g/m^3$); Q - pollutant emission rate (g/s); d_z - vertical dispersion coefficient (m); d_y - lateral horizontal dispersion coefficient (m); v - wind speed (m/s); H_e - effective height of chimney (m); x, y, z - coordinates of considered point $\mathbf{R}(x, y, z)$ (m), respectively.

The effective height of chimney corresponds to the sum of the physical height of chimney (h) with the plume height or super-elevation of plume (Δ_h):

$$H_e = h + \Delta_h \quad (2)$$

For the determination of H_e, Δ_h is calculated by considering stack downwash, buoyancy flux, crossover between momentum and buoyancy under different meteorological stability classes [3]. The dispersion coefficients, d_y and d_z, are the function of the distance from emission source and also of atmospheric stability classification. In order to determine those coefficients, Pasquill suggested classifying the atmospheric stability conditions into six typical classes [4]. For each one of the six classes, the indexes a, b, p and q can be found, which are necessary for calculating the coefficients d_y and d_z. The functions that relate these coefficients with the distance through the indexes are [1]:

$$d_y = ax^p \text{ and } d_z = bx^q \quad (3\text{-}4)$$

where, x - the distance from the emission source to considered point.

The total concentration at a receptor from a 2-D area source distribution is calculated using the narrow plume simplification by Gifford and Hunna [5]. This simplification is assumed because the upwind zone of influence affecting a receptor (an upwind oriented point source plume) is normally quite narrow in comparison with the characteristic length scale for appreciable changes in the magnitude of the area-source emission rate itself. Under these circumstances the 2-D integral that expresses the total area-source distribution to concentration at a receptor can be replaced approximately by 1-D integral. In using this area source technique, Gifford and Hunna assume area-source emissions at ground level. In RAM the area sources are allowed to have an effective height, requiring the integration to be accomplished numerically [3]. The total concentration for a given hour for a particular receptor is the sum of the estimated concentrations from each point source and (or) area source [3].

Structure of RAM 1.0 Interface: The main form of the developed RAM 1.0 Graphical User Interface consists of 18 menus, one tool bar and one status bar, respectively. These menus with their corresponding pull-down menus, if exist, are listed as follows:

File - |Open|Save|Print|Exit|; Identify; Variables - |Parameters|Constants|;
Options - |Default Opt.|Model Opts.|Printed Outputs Opts.|Other Options|;
Wind; Point Sources - |Input Each|Specify|;
Area Sources - |Input Each|Information|Break Point|Specify|;
Meteorology Data - |Read Data|Input Data|;
Receptors - |Specify Rec.|Polar CoorRec.|Honeycomb Rec.|Grid Coor. Rec.|;
Segmented Run; Show Data - |Show ID|Show Variables|Show Options|Show Wind|Show PS|
Show AS|Show MetData|Show Receptors|Show SegRun|Save Data|;
Record - |Write|Read|; Run; Sources - |Location|Emission Rate|;
Each-Hour - |Read|Display|3D Plot|2D Image|;
Average-Period - |Read|Display|3D Plot|2D Image|;
Aviewer; Help - |Contents|Search for Help on|How to Use Help|About|.

Figure 2 presents the main menu of the developed RAM 1.0 Interface.

Input of Data: The user can input the data of identify, variables, options, meteorological conditions, emission sources, receptors, and so on, through various dialog boxes by clicking 'Identify', 'Variables', 'Options', 'Wind' menus for solving his special problem. Depending on the options of the user's selections, the user needs to continuously fill in a series of dialog boxes through clicking 'Point Sources', 'Area Sources', 'Meteorology Data', 'Receptors', and (or) 'Segmented Run' menus, respectively. RAM 1.0 Software may need some input files when the user selects some data sets being read directly by RAM Algorithm code.

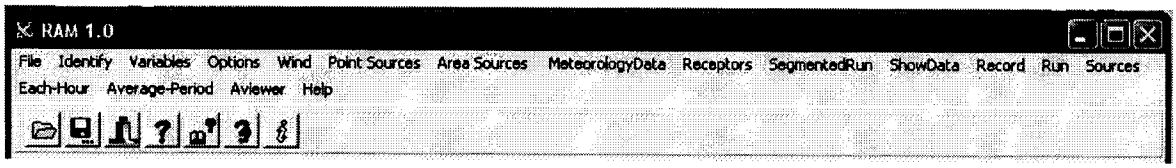

Fig. 2: Main Menu of RAM 1.0 Software

Verification and Storage of Input Data: The user can click the 'Show Data' menu and corresponding pull-down menus as well as corresponding pop up menus, if exist, to invoke a series of tables for displaying and verifying the previous inputs and selections. If need correction, the user can rewrite the input data or reselect options in relative dialog boxes. Finally, the user can save the verified input data through |Show Data|Save Data| into a text file, namely INPUT.TXT, which can be read by RAM1.0.EXE file.

Intermediate/Final Storage and Recall of Input Data: The user can click |Record|Write| to store uncompleted or completed input data into a text file, namely RECORDXXX.TXT, which can be recalled by clicking |Record|Read|. This function offers a simply approach for the user to avoid to repeat input procedure. The recalled data also can be displayed in tables by clicking |Show Data|, be corrected by clicking corresponding input dialog boxes, and be stored again by clicking |Save Data|Write| menus.

Run RAM 1.0 Executive File: By clicking 'Run' menu and manipulating in the corresponding open file dialog box, the user can operate the executive file, RAM1.0.EXE. The RAM1.0.EXE file and the INPUT.TXT file must exist within the same directory together. The various output files can be generated in the same directory.

Graphics for Input Data (3-D): Although original RAM Model provides for the user many output files in the form of table, however, the original RAM Algorithm does not present any graphical rendition route to display directly either input data or output results. The user has to analyze a lot of data and results with the help of graphical software tools. RAM 1.0 Interface has the ability to directly generate various 2-D and 3-D graphics, and also offer an additional interface to operatethe commercial graphical software package: Compaq Array Visualizer (AViewer.exe). In order to display graphically input data, the user can click two draw-down menus under 'Sources' menu, that is, 'Location' and 'Emission Rate', through which the user can generate, store and print the 3-D graphics for describing the geometric positions and emission rates of point and/or area sources. However, it is notable that fine 3-D graphics only can be obtained after careful manipulating the functions offered in two dialog boxes corresponding to these pull-down menus.

Graphics for Concentrations (2-D and 3-D): RAM 1.0 Software extends the ability of RAM Algorithm to generate a specified rectangular grid of receptors with the grid number up to 9000, which let the user can easily plot various refined 2- and 3-D graphics of concentration distributions on the interested area. By clicking |Each-Hour|Read| and |Average-Period|Read| manus, the user can select and read the output results from Unit19.txt file, for each hour computation, and Unit20.txt file, for the computation in averaging period, respectively. |Each-Hour|Display| and |Average-Period|Display| manus provide tables for displying corresponding calculated results. By clicking |Each-Hour|2D Image| and |Average-Period|2D Image| menus, RAM 1.0 Software can generate fine 2-D contour lines both in black and color and also image maps for each hour and average concentrations caused by different type of sources. Clicking |Each-Hour|3D Plot| and |Average-Period|3DPlot| menus, the user can generate fine 3-D graphics for each hour and average concentrations caused by different type of sources. The user also needs to carefully manipulate the functions offered by graph dialog boxes in order to obtain his ideal graphics.

Sample Test of EPA: The authors calculated a test sample, provided by EPA, with the aim to examine the developed RAM 1.0 Interface System and improved code. This example simulates the pollutant dispersion process in two hours, caused by the simultaneous emissions of 12 point sources and 15 area sources in a domain with 20 mile in length and 14 mile in width. The considered SO_2 emission rates of point sources are in the range from 2.56 to 299.5 g/sec. The physical stack heights of point sources are ranged from 6 to 93.6 *m*, stack inside diameters from 0.6 to 4.88 m, stack gas exit velocities from 3.81 to 24.89 m/s with the gas temperatures from 405 to 533.2 kelvin, respectively. The side lengths of area sources are 2 or 4 miles, corresponding emission rates for SO_2 are ranged from 0.51 to 8.85 g/s with the area source heights from 10 to 20 m, respectively. For the first hour, the wind speed is 6.17 m/s, ambient air temperature 269.82 kelvin, wind

direction 33 degree azimuth and mixing height 429.11 *m*; for the second hour, the corresponding meteorological parameters are 4.63 *m/s*, 271.48 *kelvin*, 23 *degree azimuth*, and 401.70 *m*, respectively. The stability class for both hours is equals to 4. By using the developed RAM 1.0 Interface, it is easy to select the options given by the test sample, to input the data and to set up the solving domain as well as to arrange the designed receptors.

RAM1.0 Graphical User Interface can provide the graphics for some of input data, which let the user to directly observe the computational situation. Figure 3 presents the source positions within the calculated domain, together with the computational coordinate systems and wind direction for the first hour. The developed RAM1.0 Interface has the ability to plot the concentrations distributions at receptors. In these figures, circles represent receptors with the vertical line lengths from X-Y plane to the circles' bottoms being equal to the values of their concentrations.

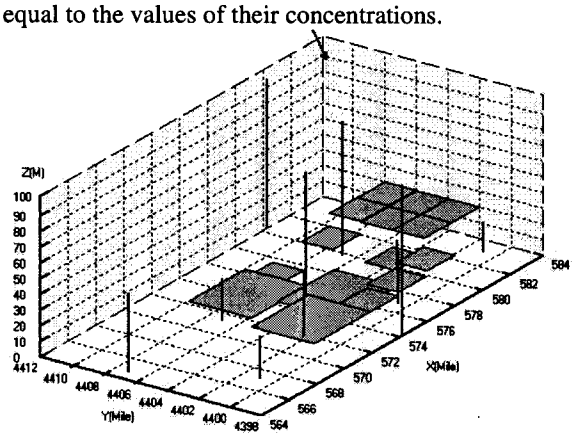

Fig. 3: Positions of Point and Area Sources for 1 hour

Those circles with zero-value of concentration are not displayed. Figure 4 demonstrates the concentrations at those receptors, given by EPA's sample for 1 hour.

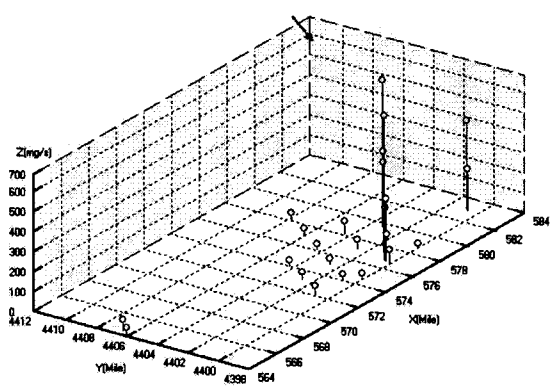

Fig. 4: SO_2 Concentration by All Sources at Receptors Given by EPA's Sample for 1 hour

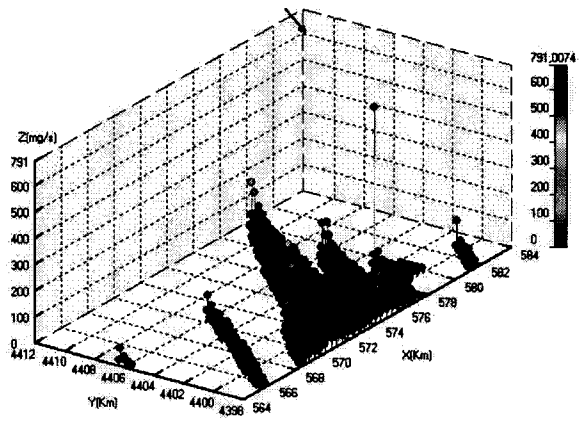

Fig. 5: Color SO_2 Concentrations by All Sources at Receptors for 1 hour

From Fig. 4, it is obvious that the values at the receptors, given by EPA's sample, are sparse, which seems not enough to generate a fine concentration distribution plot. This disadvantage of the original RAM Model is mainly caused by the limitation of original RAM Algorithm, where the defined total number of receptors is merely 180. Due to the quick development of microcomputers, it is possible and necessary to improve the original RAM Algorithm, in order to form refined graphics with higher resolution and better quality. Through our improvements, the total receptor number, generated by the developed RAM 1.0 Interface, has been greatly increased up to 9000. Figure 5 presents the concentration distributions at a denser receptor grid, produced by all sources, for 1-Hour, the used number of receptors is equal to 2500 (50×50).

Except for the ability to generate 3-D plots for some input data and concentrations at receptors, the developed RAM 1.0 Software also can provide 2-D contour lines and image maps. Figure 6 presents the contour lines caused by all sources for 1 hour.

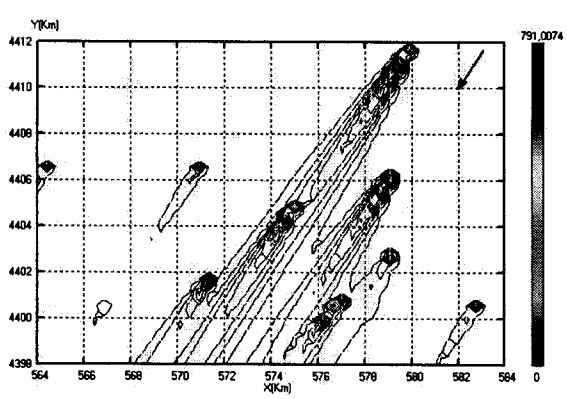

Fig. 6: Color Contour Lines of SO_2 Concentrations by All Sources for 1 hour

RAM 1.0 Software also can draw refined 3-D concentration distributions. Figure 7 presents the produced surface plot of concentration caused by all sources for 1 hour.

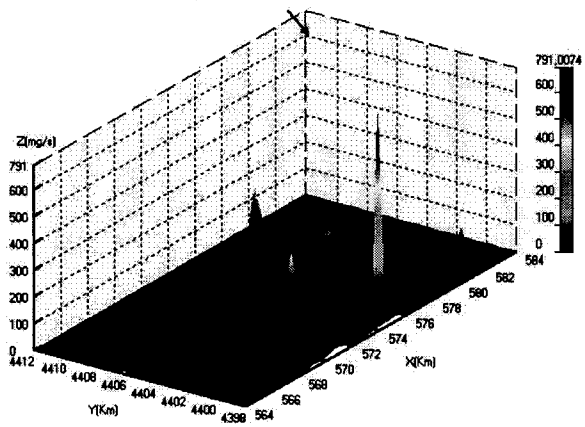

Fig. 7: Surface Plot of SO_2 Concentrations by All Sources for 1 hour

DISCUSSION

Using the developed RAM 1.0 Software, the reports simulated the SO_2 concentration distributions of EPA's sample. Only a part of calculated results caused by all sources at 1-hour have been presented in this study. RAM 1.0 Software can plot various fine graphics to illustrate solved concentration distributions. It is clean that the strong graphical functions of RAM Interface, either 2-D or 3-D, are quite robust. Actually, the developed RAM 1.0 Graphical User Interface has strong ability to generate much fine plots, which depend on the used rectangular grid number of receptors. In addition, an obvious benefit to use the specially developed graphical function of RAM 1.0 Interface is to make the produced plots with a better professional level. For example, although using commercial graphical software also can plotted the distributions of calculated concentration fields, however, one of the important parameters in the atmospheric dispersion modeling, the wind direction, generally cannot be expressed.

By using the data of the EPA's sample test, it is easy and convenient to simulate pollutant dispersion caused by various point sources and area sources. Making a powerful interface allows the previously developed Fortran original program, such as the published RAM Algorithm, to work under windows-based environment and to produce fine graphics for input data and output results. The improvement of RAM Algorithm, mainly to crease the number of receptors from 180 to 9000, provide for the user the possibility to plot concentration distribution graphics with higher resolutions. This improvement has great practical significance for various users of RAM Model to calculate and analyze their particular problems.

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