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Use of Geographic Information System Tools for Improving Atmospheric Emission Inventories of Biogenic Source

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Biogenic source emissions refer to naturally occurring emissions from vegetation, microbial activities in soil, lightening, and so on. Vegetation is especially known to emit a considerable amount of volatile organic compounds into the atmosphere. Therefore, biogenic source emissions are an important input to photochemical air quality models. Since most biogenic source emissions are calculated at the county-level, they should be geographically allocated to the computational grid cells of a photochemical air quality model prior to running the model. The traditional method for the spatial allocation for biogenic source emissions has been to use a "spatial surrogate indicator" such as a county area. In order to examine the applicability of such approximations, this study developed more detailed surrogate indicators to improve the spatial allocation method for biogenic source emissions. Due to the spatially variable nature of biogenic source emissions, Geographic Information Systems(GIS) were introduced as new tools to develop more detailed spatial surrogate indicators. Use of these newly developed spatial surrogate indicators for biogenic source emission allocation provides a better resolution than the standard spatial surrogate indicator.

Key words : vegetation, microbial activities, photochemical air quality model.

1. Introduction

Emission sources are broadly classified as either anthropogenic or biogenic sources. Anthropogenic sources can be further sub-classed as point, area, and mobile source emissions based on their source characteristics. Point source emissions refer to emissions occurring at specified locations because of specific processes(e.g., chemical plants, refineries, power plants, etc.). Area source emissions include emissions from sources considered too small or too numerous to be handled individually as point source emissions(e.g., business or residential area emissions). Mobile source emissions are due to non-stationary sources including on-road motor vehicles, aircraft, locomotives, and marine vessel emissions. Emissions from off-road vehicles such as constructional, agricultural, recreational, or gardening vehicles are treated as area source emissions1). Biogenic source emissions refer to emissions occurring from natural sources that are mostly vegetation2). Biogenic source emissions are important in determining the background levels of air pollutants. They also contribute greatly to rural and regional air pollution. Therefore, the spatial and temporally accurate estimation of these emissions is very important for use with grid-based photochemical air quality models.

Biogenic Emissions Inventory System Version 1(BEIS1.0) was developed in 1991 by the American Environmental Protection Agency(US EPA)2). The purpose for developing the model was to estimate hourly-gridded biogenic emissions that could be used in photochemical air quality modeling applications. This model was subsequently updated to BEIS2.0.

For similar emissions rates, several versions of the BEIS model have been developed to address various modeling objectives. To estimate regional-scale biogenic emissions, the Regional Oxidant Model(ROM)- and the Regional Acid Deposition Model(RADM)-BEIS were developed. Meanwhile, the Urban Airshed Model(UAM)-BEIS has been utilized to calculate urban-scale biogenic emissions. Other BEIS models include a personal computer version of PC-BEIS2.2 and the BIOgenic Model for Emissions Estimation(BIOME). The PC-BEIS was developed for personal computer users to prepare a biogenic emissions inventory report. BIOME is one of several emission inventory models included in the Emission Inventory System 95(EMS-95)[3].

These biogenic emission models commonly calculate volatile organic compounds(VOC) and nitrogen monoxide(NO) emissions from vegetation and soil. The VOC emissions from vegetation are composed of three groups : isoprene, monoterpene and other VOC. The types of vegetation considered in the BEIS models include 75 tree genera, 17 agricultural crops, and grass. The required inputs to the BEIS models are the foliar density and emission factors of each vegetation type, surface meteorology, and ambient temperature.

BEIS models calculate the emission rates of vegetation through[2,4,5] :

$$ER_i = \sum_{j=1}^{n} (A_j \cdot FF_j \cdot EF_{ij} \cdot F(S,T)) \quad (1)$$

Where,

ER = emission rate(g/hour),
i = chemical species(e.g., isoprene, monoterpene, other VOC and NO)
A = area of vegetation(m^2),
j = vegetation type(see Table 2),
FF = foliar density factor(g leaf biomass) (m^{-2}),
EF = emission factor(g leaf biomass^{-1})(hour^{-1}),
$F(S, T)$ = environmental factor(solar radiation S, and leaf temperature T).

When non-forest emissions are calculated, the foliar density factor in the above simplified equation is assumed to be one.

To geographically allocate biogenic source emissions, the standard approach is to use a "top-down" method : county level emissions are calculated and then disaggregated to a "grid level", i.e. to the resolution of a computational cell of a grid-based air quality model using a spatial surrogate indicator such as the county-area fraction. The county-area fraction is defined as the ratio of a county area in a grid cell to the entire area of the county. However, the standard spatial allocation methodology employing the county-area fraction may not be accurate, since the area of a county does not properly represent the different levels of biogenic source emissions resulting from the varying vegetation distribution in the county. As a result, there is a need to develop more accurate spatial surrogate indicators for biogenic source emissions.

This study discusses the conventional spatial allocation method and problems associated with this method. More detailed spatial surrogate indicators were then developed to improve the conventional spatial allocation method. Finally, a comparison of the conventional and newly developed spatial allocation methods was performed to determine which method could provide a more accurate emission estimation.

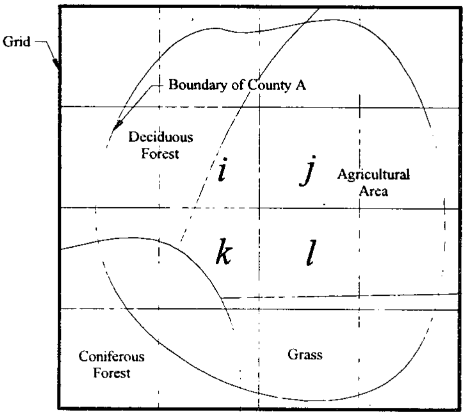
2. Methodology

2.1. Development of New Spatial Surrogate Indicators

BEIS2.0 was designed to use only one default spatial surrogate indicator, the county-area fraction. However, the county-area fraction evenly assigns biogenic emissions to all grid cells except for the grid cells on the boundaries of counties. As a result, this spatial surrogate indicator cannot properly reflect the different vegetation emission levels resulting from a varying spatial distribution of vegetation. Fig. 1 illustrates the standard spatial allocation method with an example. The biogenic emissions and area of a county "A" were assumed to be 350 tons per day and 300 km^2, respectively. The areas of grid cells i, j, k and l were assumed to be 25 km^2. In this case, the county-area fractions allocated the same level of biogenic source emissions, 29.2 tons per day, to all i, j, k, and l grid cells.

Accordingly, six representative spatial surrogate indicators were developed for a more accurate assignment of various emissions levels caused by different vegetation distributions or land use/land covers :

1. Forest fraction,
2. Deciduous forest fraction,
3. Coniferous forest fraction,
4. Agricultural fraction,
5. Grass land fraction,
6. Other land use fraction.



Emissions of County A, 350 tons/day
County Area of A, 300 sq. km
Area of Grid Cell Each, 25 sq. km

Emissions of grid cells *i, j, k, and l* = 350 (25/300) = 29.2 tons/day

Fig. 1. Schematic illustration of the standard spatial allocation method for biogenic source emissions.

For the application of these newly developed spatial surrogate indicators, the county-level biogenic emissions were estimated using a BEIS model, thereafter, the emissions were allocated to grid cells using the developed spatial surrogate indicators. The process can be formulated as the following equation :

$$M_g = \sum_{i=1}^{6} M_{ci} \cdot f_i \qquad (2)$$

Where,

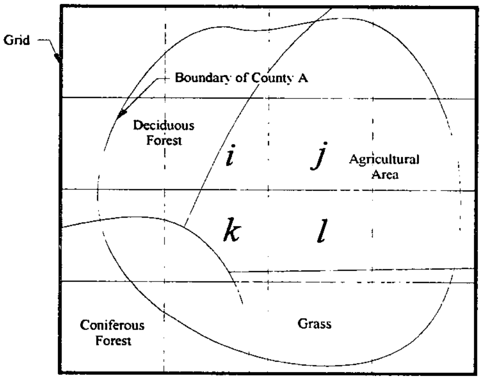
M_g = mass of biogenic source emissions in a grid cell,

i (1 = forest, 2 = deciduous forest, 3 = coniferous forest, 4 = agricultural area, 5 = grass, and 6 = other land use),

M_c= mass of biogenic emissions in a county (tons/day),

f = spatial surrogate indicator fraction.

An application example of the proposed method is shown in Fig. 2. In Fig. 2, grid cell k in county "A" was assumed to be composed of deciduous forest, coniferous forest, agricultural area and grass land. Grid cell l was assumed to be composed of agricultural area and grass land. By using the above equation, the emissions of grid cells k and l were estimated at 32.7 and 15.1 tons per day, respectively. The estimated emissions for grid cells k and l using this developed spatial allocation method were considerably different from those using the standard spatial allocation method(i.e., 29.2 tons per day for grid cells k and l).



Emissions of County A. 350 tons/day
County Area of A. 300 sq. km
* Deciduous forest emissions. 150 tons/day
* Deciduous forest area. 80 sq. km
* Coniferous forest emissions. 100 tons/day
* Coniferous forest area. 50 sq. km
* Agricultural emissions. 70 tons/day
* Agricultural area. 100 sq. km
* Grass emissions, 30 tons/day
* Grass area. 70 sq. km

Area of grid cell *k. 25 sq. km*
* Area of grid cell *k* in decidu
* Area of grid cell *k* in conifer
* Area of grid cell *k* in agricul
* Area of grid cell *k* in grass.
Area of grid cell *l. 25 sq. km*
* Area of grid cell *l* in agricult
* Area of grid cell *l* in grass. 9

Emissions of grid cell *k* = 150 (5/80) + 100 (8/50) + 70 (8/100) + 30 (4/70)
Emissions of grid cell *l* = 70 (16/100) + 30 (9/70) = 15.1 tons/day

Fig. 2. Schematic illustration of the developed spatial allocation method for biogenic source emissions.

2.2. Tools and Data

Geographic Information Systems

The development of the new spatial surrogate indicator involved Geographic Information System (GIS) tools. GIS is a set of computer programs which are able to produce, store, manipulate, retrieve, and display digitized geographical maps and data[6-8]. ArcView and Arc/Info(ESRI, Inc.), MapInfo(MapInfo Co.), and InterGraph(Geomedia Co.) are widely used commercial GIS software packages. GIS provides the same information as conventional paper maps : how geographic features such as rivers, buildings, and roads are located on or near the surface of the Earth and how far the geographic features are apart from each other. However, the real power of GIS comes not only from its ability to store geographic data, but also from its ability to analyze them efficiently and conveniently. The GIS functions used in this research measure specific land use/land cover areas in the real world and spatially display biogenic source emissions.

Geographic Information Retrieval and Analysis Systems(GIRAS)

GIRAS[9-12] provides land use and land cover data for most of the United States and Hawaii. The United States Geological Survey(USGS) has compiled and organized the standard topographic maps of 1 : 250,000, or 1 : 100,000 in some cases such as Hawaii. The land use and land cover describes the vegetation, water, natural surface, and cultural features on the land surface from the mid-1970s to the early 1980s. The data are available in two different formats : GIRAS and Composite Theme Grid(CTG) format. The GIRAS format uses polygons, i.e., the vector data model, to represent geographic features such as land use/land cover. The CTG format employs grid cells in denoting geographic features like a raster data model. Two levels of hierarchical systems are mapped and coded in land use/land cover classifications : Level 1(general classification, e.g., agricultural land) and Level 2(more specific classification, e.g., cropland and pasture, orchards, vineyards, horticultural areas, etc.). The GIRAS land use/land cover data can be obtained through File Transfer Protocol (FTP) from the US EPA.

New Jersey Integrated Terrain Unit Maps(NJ ITUM)

In 1986, the New Jersey Department of Environmental Protection(NJDEP) began a project to create a state-wide environmental database for its GIS applications. The project was accomplished in 1995 by the Environmental System Research Institute(ESRI) as the main contractor and Aerial Information Systems(AIS) as the subcontractor. The NJDEP's environmental database provides four data layers as land use/land cover, soils, geology, and flood-prone areas for the counties of the entire State of New Jersey. The land use/land cover was produced through a photo-interpretation of 1986 Color Infrared(CIR) aerial photography and a variety of collateral county-wide data sets called Integrated Terrain Unit Maps(ITUM)[13]. The spatial resolution of the land use/land cover of NJ ITUM is 1.5 acres that are equivalent to a minimum width of 85 feet. The other three data layers of soils, geolog,y and flood-prone areas were developed by recompiling existing maps. The data quality was assured by performing field verification. The level 1 and level 2 classifications of the land use/land cover of NJ ITUM data correspond to the GIRAS classification scheme, however, NJ ITUM data provide more detailed land use/land cover categories in level 3 than GIRAS. The data are available in the form of CDs from NJDEP.

3. Results and Discussion

Since two land use/land cover data sources, GIRAS and NJ ITUM, are available for the State of New Jersey, the two data sources were compared to assess their usefulness in extracting land use/land cover information for this study. The comparison is given in Table 1. As shown in Table 1, GIRAS is a national land use/land cover database developed using mostly 1970s data, while NJ ITUM is a state database based on 1986 and 1987 data sets. The spatial resolution and highest number of detailed land use/land cover categories are 10 acres and 36 categories, respectively, for GIRAS in comparison with 1.5 acres and 134 categories for NJ ITUM. This comparison indicates that NJ ITUM data are able to provide more up to date and detailed land use/land cover information for New Jersey.

County area fractions as the standard spatial surrogate indicator were provided by the US EPA. The proposed six spatial surrogate fractions were developed using GIS tools and the NJ ITUM land use/land cover data. The UAM-BEIS2.0 model was used to calculate the biogenic emissions and demonstrate the advantage of the developed spatial allocation method. The State of New Jersey was considered as a test case for this study. Gridded isoprene and NO emission rates using the standard spatial allocation method are presented in Fig. 3 and 5. Fig. 4 and 6 show the gridded isoprene and NO emissions using the newly developed spatial allocation method. The biogenic isoprene and NO emission rates are grouped into several ranges in terms of their gram_mole per hour.

The standard emission allocation method evenly spread the isoprene and NO emissions to grid cells within county boundaries, as shown in Fig. 3 and 5, whereas the newly developed spatial allocation method assigned higher emissions(i.e., more than 1,000gm_mole/hour for isoprene a and more than

Table 1. Comparison of GIRAS and NJ ITUM land use and land cover data.

	GIRAS	NJ ITUM
Data Developer/Provider	USGS	NJDEP
Extent of Coverage	Most areas of the US and Hawaii	The State of New Jersey
Maximum Number of Land Use and Land Cover Categories	Level 1 - 9 categories Level 2 -36 categories	Level 1 - 7 categories Level 2 - 26 categories Level 3 -134 categories
Spatial Resolution	10 acres	1.5 acres
Date of data	mid 1970s to early 1980s	1986 and 1987
Data Processing	Digitization of interpreted aerial photographs and earlier land use maps and field survey	The same as GIRAS

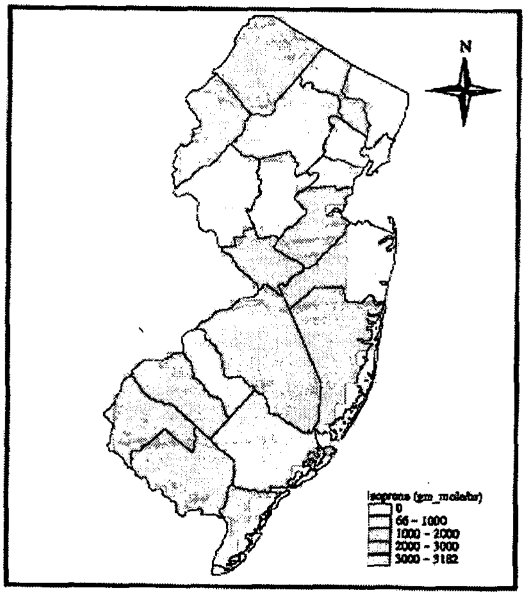


Fig. 3. Plot of gridded biogenic isoprene emissions using the standard spatial allocation method.

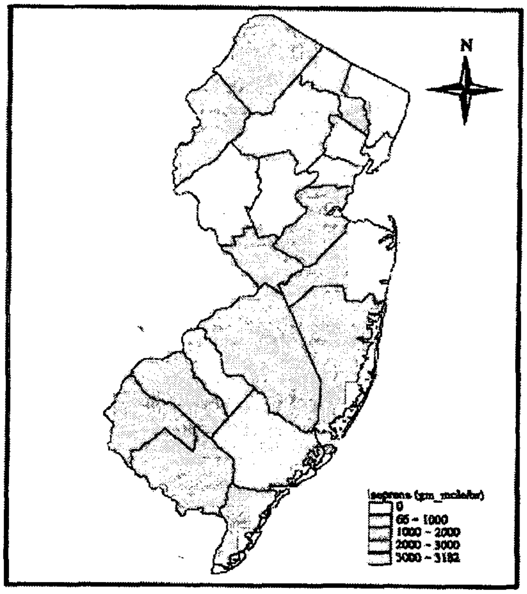


Fig. 4. Plot of gridded biogenic isoprene emissions using the standard spatial allocation method.

15 gm_mole/hour for NO) to specific areas, as shown in Fig. 4 and 6. The land use/land cover map of NJ ITUM suggests that these specific areas were forest areas for isoprene in Fig. 4 and agricultural areas for NO in Fig. 6. This finding corresponds to the fact that forest trees generally have higher isoprene emissions, and agricultural plants generally have higher NO emissions than any other air pollutants, as seen in Table 2.

Furthermore, the newly developed spatial allocation method predicted the maximum isoprene and NO emission rates approximately three times higher and two times higher, respectively, than the standard spatial allocation method : 3,182 gm_mole per hour for isoprene and 61 gm_mole per hour for NO with the standard spatial allocation method, yet 9,347 gm_mole for isoprene and 122 gm_mole for NO with the newly developed spatial allocation

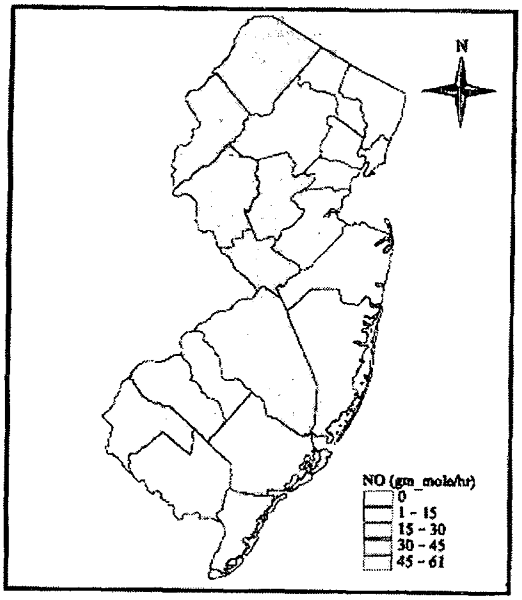


Fig. 5. Plot of gridded biogenic nitrogen monoxide (NO) emissions using the standard spatial allocation method.

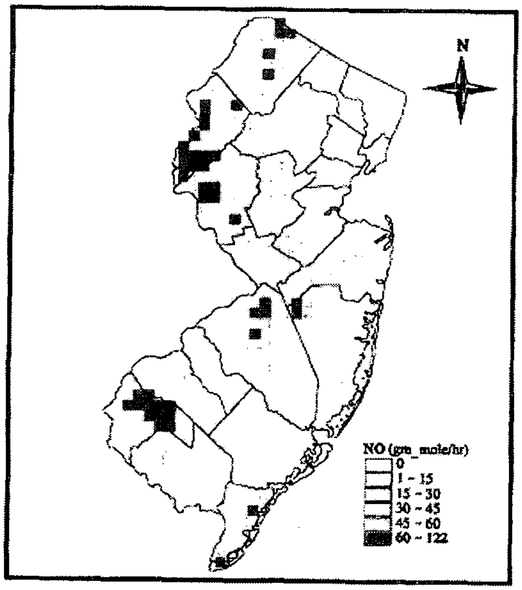


Fig. 6. Plot of gridded biogenic nitrogen monoxide (NO) emissions using the developed spatial allocation method.

method. This result indicates that the standard spatial allocation method may considerably underestimate biogenic source emissions rates. Consequently, photochemical air quality models may underpredict the ozone concentrations when underestimated biogenic source emissions rates are used as the input to the models. The accuracy of estimated maximum air pollutant emissions or concentrations has a very important regulatory significance in that current attainment standards for air pollutants are based on the maximum concentrations of air pollutants, plus the effectiveness of proposed air pollutant control strategies in State Implementation Plans(SIP) is determined based on the estimated maximum concentrations from a regulatory model(e.g., Urban Airshed Model).

4. Summary

The findings obtained through this study can be summarized as follows :

1) NJ ITUM data provide more updated and detailed land use/land cover information than GIRAS data. This result is not unexpected since a state database is generally a more updated and detailed data source than a national database.

2) The use of the newly developed spatial allocation method for biogenic source emissions appears to be more physically consistent than the standard spatial allocation method. It was also confirmed that GIS technology can be used as useful tools for developing detailed spatial surrogate indicators for improving biogenic source emission inventories.

3) The percentage differences in the calculated isoprene and NO maximum emissions resulting from using the two different spatial allocation methods for biogenic source emissions were 194% and 100 %, respectively.

4) The calculated maximum emission difference resulting from the use of the two different spatial allocation methods will have a significant impact on the calculated air quality. Accordingly, further studies are required for a performance evaluation of air quality models using this newly refined spatial allocation method.

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I would like to express my sincere gratitude to

Table 2. Selective emission factors for vegetation[2].

		Emission Factor			
	Description	Isoprene	Monoterpene	VOC	NO
Forest Trees	Abies (fir)	170.0	5100.0	2775.0	4.5
	Acacia	79.3	2380.0	1295.0	4.5
	Acer (maple)	42.5	680.0	693.7	4.5
	Boreal forest	910.0	713.0	755.0	4.5
	Casuarina (Austl pine)	29750	42.5	693.7	4.5
	Conifer forest	1550	1564.0	1036.0	4.5
	Eucalyptus	29750.0	1275.0	693.7	4.5
	Hardwood forest	8730.0	436.0	882.0	4.5
	Liquidambar (sweetgum)	29750.0	1275.0	693.7	4.5
	Mixed forest	11450.0	1134.0	1140.0	4.5
	Northern mixed forest	10150.0	1100.0	850.0	4.5
	Picea (spruce)	23800.0	5100.0	2775.0	4.5
	Pinus (pine)	79.3	2380.0	1295.0	4.5
	Planera (water elm)	42.5	42.5	693.7	4.5
	Platanus (sycamore)	14875.0	42.5	693.7	4.5
	Populus (aspen)	29750.0	42.5	693.7	4.5
	Prunus (cherry)	42.5	42.5	693.7	4.5
	Pseudotsuga (douglas fir)	170.0	2720.0	2775.0	4.5
	Quercus (oak)	29750.0	85.0	693.7	4.5
	Salix (willow)	14875.0	42.5	693.7	4.5
	Southeast/Western Deciduous forest	10750.0	530.0	910.0	4.5
	Southeast Mixed Forest	17000.0	1500.0	1250.0	4.5
Agricultural plants	Barley	7.6	19.0	11.4	256.7
	Corn	0.5	0.0	0.0	577.6
	Cotton	7.6	19.0	11.4	256.7
	Oats	7.6	19.0	11.4	256.7
	Potato	9.6	24.0	14.4	192.5
	Peanut	102.0	255.0	153.0	12.8
	Rye	7.6	19.0	11.4	12.8
	Sorghum	7.8	19.5	11.7	577.6
	Soybean	22.0	0.0	0.0	12.8
	Tobacco	0.0	58.8	235.2	256.7
	Wheat	15.0	6.0	9.0	192.5
Grass	Grass	56.2	140.5	84.3	57.8

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References

[1] U. S. Environmental Protection Agency. *User's Guide for the Urban Airshed Model, Volume IV : User's Manual for the Emissions Preprocessor System 2.0.* Office of Air Quality Planning and Standards, Research Triangle Park, NC, June 1992, EPA Publication No. EPA-450/4-90-007D(R).

[2] EC/R Incorporated. Urban Airshed Model

(UAM) Biogenic Emissions Inventory System Version 2(BEIS2) User's Guide, September 28, 1995. EC/R Project No. AQM-108.

[3] R. A. Emigh and J. G. Wilkinson. *The Emissions Modeling System(EMS-95) User's Guide.* Alpine Geophysics, July 1, 1995.

[4] Radian Corporation. *Biogenic Sources Preferred Methods.* Technical Report, May 1996. Final Report

[5] R. L. Tanner, K. K. Mayenkar, R. J. Dickson and M. R. Rose. *Modeling Biogenic Hydrocarbon Emissions Current Status and Recent Advances.* Durham, North Carolina. Presented at the AWMA International Specialty Conference on Emission Issues of the 1990s.

[6] Environmental System Research Institute. *ARC/INFO Data Management, Concepts, Data Models, Database Design, and Storage.* ESRI, 380 New York Street, Redlands, CA 92373, USA, 1994.

[7] Environmental System Research Institute. *Understanding GIS, The ARC/INFO Method,* ESRI, 380 New York Street, Redlands, CA 92373, USA, 1994.

[8] W. E. Huxhold. *An Introduction to Urban Geographic Information System. Oxford University Press,* 1991.

[9] ftp://ftp.epa.gov/pub/EPAGIRAS

[10] http://www.epa.gov/regionoz/gis/atlas/giras_lu.html

[11] http://edcwww.cr.usgs.gov/glis/hyper/guide/1_250_lulc.

[12] http://www.usgs.gov.

[13] New Jersey Department of Environmental Protection. *User's Guide.* Bureau of Geographic Information and Analysis, Office of Information Resources Management, NJDEP, CN 428, Trenton, NJ 08625, March 7, 1996.